SPGR Sub-Project Completion Report

on

Coordinated Sub-project on Carbon Sequestration in Soils of Bangladesh (BINA Component)

Duration : March 2010 to November 2014

Executing Organization

Soil Science Division
Bangladesh Institute of Nuclear Agriculture
Mymensingh

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Abbreviation

AEZ	:	Agroecological zone
ANOVA	:	Analysis of variance
NH_4OAC	:	Ammonium oxalo acetate
AWD	:	Alternate wetting and drying
BAU	:	Bangladesh Agricultural University
$BaCl_2$	:	Barium chloride
$BD = \rho_g$	:	Bulk density
BINA	:	Bangladesh Institute of Nuclear Agriculture
Binadhan-7	:	Bangladesh Institute of Nuclear Agriculture dhan-7
B	:	Boron
BRRI dhan29	:	Bangladesh Rice Research Institute dhan29
d	:	day
DAT	:	Days after transplanting
C	:	Carbon
C_3	:	C-3 plants
C_4	:	C-4 plants
CD	:	Cowdung
CF	:	Continuous flooding
C:N	:	Carbon nitrogen ratio
cm	:	Centimeter
CO_2	:	Carbon dioxide
CV	:	Coefficient of variation
FAPAD	:	Foreign Aided Project Audit Directorate
FC	:	Flooding condition
g	:	Gram
GHG	:	Greenhouse gas
GPS	:	Global positioning system
HL	:	Highland
HCl	:	Hydrochloric acid
ha	:	Hectare
kg	:	Kilogram
k	:	Degradation constant
LL	:	Lowland
LT	:	Land type
LSD	:	Least significance difference
LoA	:	Letter of agreement
MC	:	Moist or field capacity

Mg	:	Megagram
MHL	:	Medium highland
MLL	:	Medium lowland
mg	:	Milligram
ml	:	Milliliter
MT	:	Minimum tillage
N	:	Nitrogen
$NaHCO_3$	:	Sodium bicarbonate
NATP	:	National Agricultural Research Project
NaOH	:	Sodium hydroxide
NRS	:	No residue
OC	:	Organic carbon
OR	:	Organic residue
p	:	Probability
P	:	Phosphorus
PCU	:	Project Coordination Unit
pH	:	Soil reaction
PM	:	Poultry manure
PIU-BARC	:	BARC-Project Implementation Unit-Bangladesh Agricultural Research Council
PVC	:	Polyvinyl chloride
RDF	:	Recommended doses of chemical fertilizers
STB	:	Soil Test Based Fertilizers
RSI	:	Residue incorporation
RSM	:	Residue mulch
RS	:	Rice straw
RR	:	Rice root
SE	:	Standard error
SRDI	:	Soil Resources Development Institute
SS	:	Sugarcane straw
SOC	:	Soil organic carbon
SOE	:	Statement of expenditure
TT	:	Traditional tillage
Tk.	:	Taka
T.aman	:	Transplanted aman
VLL	:	Very lowland
W	:	Water level

Executive Summary

Coordinated Project on Carbon Sequestration in Soils of Bangladesh: Bangladesh Institute of Nuclear Agriculture (BINA) component, a sponsored public goods research project (SPGR), received fund from the NATP: Phase 1, Bangladesh Agricultural Research Council. BINA component officially launched this project on April 2010 and continued up to November 2014. Carbon sequestration is essential to improve soil quality, increase agronomic productivity and use efficiency of inputs like fertilizers and water thus helps to maintain or restore the capacity of soil to perform its production and environmental functions on a sustainable basis. In this regard, this project was undertaken some experiments: Assessment of existing carbon stock in soils of 10 AEZs in Bangladesh; Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition with and without crop; Carbon accumulation efficiency in soil using C_3 and C_4 crop residues; Carbon sequestration in soils under different tillage, crop establishment method and rice straw management and Effect of different organic manures/residues and fertilizer management on carbon sequestration under rice-rice cropping pattern.

A total of 2400 samples were collected to assess carbon stock in soil from 10 AEZs (AEZ 11-20) of Bangladesh. In general, soil organic carbon (SOC) content (%) decreased with the increase of soil depth irrespective of land types. The SOC (%) and stock (t ha^{-1}) were found higher in the very lowland than in highland, medium highland and medium lowland. Among the 10 AEZs, the highest SOC stock (1.40 million tones ha^{-1}) was found in AEZ 13 irrespective of land types.

Different organic residues were tested to quantify CO_2-C emission under two moisture regimes. The rate of CO_2-C emission was higher in earlier stage of incubation irrespective of organic resources both in flooding and moistened conditions. However, among the organic residues poultry manure in combination with soil produced more CO_2-C than cow dung, rice straw and rice root with the mixture of soil.

Organic residues (rice straw, rice root, cow dung and poultry litter) with five levels of carbon (0.0, 0.5, 1.0, 1.5 and 2.0 t ha^{-1}) were tested using alternate wetting and drying (AWD) and continuous flooding (CF) conditions using rice crop. Flooding condition produced higher grain yield than alternate wetting and drying condition. Continuous flooding condition was found more efficient to accumulate SOC in soils than alternate wetting and drying condition. Among the organic residue doses, 2.0 t C ha^{-1} produced the maximum organic carbon content in soil.

Five levels of carbon (0.00, 0.48, 0.96, 1.44 and 1.92 t C ha^{-1}) mixed with soil were tested using field capacity (W_1) and continuous flooding (W_2) conditions to determine the decomposition trend of fresh rice straw and sugarcane residues. Rice straw produced more CO_2–C than sugarcane residue. Sugarcane residue (C_4) stabilized (42%) more carbon in soil than rice straw (C_3) residue. So, sugarcane residue has good capacity to sequestrate more carbon in soil than rice straw residue.

Carbon sequestration in soils under different tillage options and rice straw management practices was tested in field condition. Minimum tillage produced the maximum SOC in soil. Rice straw incorporation and mulch significantly produced SOC (17 and 10%) over no crop residue treated plots respectively after five crop seasons. Minimum tillage sequestrated the maximum SOC (0.039 t C ha^{-1} yr^{-1}) over traditional tillage. Recommended dose of chemical fertilizer treated plots produced the highest grain yield of rice.

The effect of different organic residues and fertilizers management practices were tested to quantify carbon sequestration under rice cropping system. Application of organic residues with integrated plant nutrition system emitted more carbon dioxide than soil test based chemical fertilizer after five crop seasons. Rice straw, cow dung, poultry manure and STB fertilizer produced 24, 24, 20 and 12% more organic carbon over control. Poultry manure treated plots produced the higher grain yield of rice than other treatments.

1.	**Sub-Project title**	**:**	**Carbon sequestration in soils of Bangladesh**
2.	**Principal Investigator**	**:**	Dr. Md. Belal Hossain Senior Scientific Officer
3.	**Full address**	**:**	Soil Science Division Bangladesh Institute of Nuclear Agriculture (BINA) BAU campus, Mymensingh-2202 Phone: 01746064514, e-mail: belalbina@gmail.com
4.	**Duration of the sub-project with revision**	**:**	From March 2010 to November 2014
5.	**Date of approval** (by the Executive Council/ signing of LoA with revision)	**:**	April 2010
6.	**Total approved Budget with revision (Taka)**	**:**	51,72,760.00
	Total fund received (Tk)	**:**	37,50,890.00
	Total fund Spent (Tk)	**:**	37,50,890.00
	Unspent/Balance of fund (Tk)	**:**	Nil

7. Justification of undertaking the sub-project:

Before Green Revolution, farmers' of Bangladesh used low input crop varieties for their food production and cropping intensity was also very low as a result, soil quality such as organic matter and essential plant nutrients reserve didn’t affect by the above mentioned practices. Now-a-days, farmers' use high input modern crop varieties with little or no use of organic residues for their crop production as well as cropping intensity is also high. In these consequences the highest depletion of soil carbon has been observed in soils of Meghna river floodplain (35%), followed by Madhupur tracts (29%), Brahmaputra floodplain (21%), Old Himalayan piedmontplain (18%) and Gangetic floodplain (15%) during 1967-1995 (Ali *et al.*,1997). Decline in SOC, is an increasing scientific issue in Bangladesh threatening soil quality and environmental health because good soil fertility and environmental health are needed to feed our overgrowing people through increasing crop production.

Soil organic carbon (SOC) is a key indicator of fertility and quality of arable fields. It has crucial role in nutrient cycling, improving soil physical, chemical and biological properties, crop productivity and reducing green house gases (GHGs) (Bhattacharyya *et al.*, 2009; Mikhaillova and Post, 2006). Soils also are the largest carbon reservoirs of the terrestrial carbon cycle. About three times more carbon is contained in soils than in the

world's vegetation and soils hold double the amount of carbon that is present in the atmosphere. Moreover, worldwide the first 30 cm of soils hold 1500 Pg carbon; for India the figure is 9 Pg. But the information of soil carbon stock is not available in different depths in different AEZs of Bangladesh to formulate effective land use and management practices for the crop production. Another option of land management practices, water level is one of the most important factors for decomposition of organic residues in soil. A number of studies have shown that soil moisture could greatly enhance organic residues decomposition and CO_2 flux or reduce it (Iqbal *et al.*, 2009; Tulina *et al.*, 2009). On the other hand, different organic residues have different capacities to improve soil carbon due to their compositional variations. Extensive experimentation should be conducted to gain better understanding of decomposition constant rate (k) for selecting effective carbon sequester in soil and reduce environmental pollution under different water levels with different organic residues. Soil plowing and rearrangement with clean surface from preceding crop residues and weeds is also a good technique, which aims at a creation of better physical conditions for crop growth. Nevertheless, it causes reversible changes as water loss and organic matter decline. No and minimum tillage are considered as alternative techniques for tilling the soil. Despite no tillage disadvantages, as bulk density and soil compaction, which may negatively influence nutrients uptake with poor performance of root growth, it is advantageous over conventional tillage in some cases, as conservation tillage. To escape from no tillage disadvantages and save time for sowing a crop, reduced tillage may be used as an important alternative. Moreover, sole use of chemical fertilizers is caused the deterioration of soil physico-chemical and biological properties especially nitrogenous fertilizer. The applied N is not all taken by the crop plant; the efficiencies of nitrogenous fertilizers are very low, approximately 32-35%. A large proportion is lost due to ammonia volatilization, denitrification and leaching. On the other hand, organic manures may increase soil fertility and crop productivity by changes in soil physical and chemical properties including nutrient bioavailability, soil structure, water holding capacity, cation exchange capacity, soil pH and activity of microbial community. But single use of organic manure may not help to sustain of crop production. So, a balanced with integrated use of organic and inorganic nutrient sources can help to sustain crop production. Depletion of nutrients and poor organic matter contents of Bangladesh soils can only be replenished by integrated use of fertilizers and effective land management practices to ensure food security and improve soil health. However, information on soil carbon balance in the major cropping pattern such as rice cropping system under different AEZs of Bangladesh is not well documented, which needs to be estimated.

8. Sub-project objective(s):

i. To quantify the present status of carbon in soils in thirty agro-ecological zones of Bangladesh
ii. To establish the relationship among cropping systems and management practices with the soil carbon stock and systems productivity
iii. To determine the degree of carbon sequestration in soils using C_3 and C_4 crop residues
iv. To determine the effects of different cropping systems and management practices on soil carbon stocks
v. To evaluate the degree of carbon sequestration using integrated nutrient management practices

9. Methodology:

The following approaches and methodologies were adopted to fulfill the objectives of the proposed research project.

9.1. Assessment of existing carbon stock in soils of 10 AEZs in Bangladesh

Experiment was conducted to quantify the existing carbon status from different AEZs of Bangladesh. Soil samples were collected from ten (10) AEZs: AEZ 11. High Ganges River Floodplain, AEZ 12. Low Ganges River Floodplain, AEZ 13. Ganges Tidal Floodplain, AEZ 14. Gopalganj-Khulna Bils, AEZ 15. Arial Bil, AEZ 16. Middle Meghna River Floodplain, AEZ 17. Lower Meghna River Floodplain, AEZ 18. Young Meghna Estuarine Floodplain, AEZ 19. Old Meghna Estuarine Floodplain and AEZ 20. Eastern Surma-Kusiyara Floodplain. A total of 2400 soil samples were collected during 2010–2013. Upazila, mouja and land type were selected using “Thana Nirdeshika” of Soil Resource Development Institute (SRDI) of Bangladesh. Two hundreds forty (240) soil samples were collected from (2 upazilas × 3 moujas × 10 samples per available land types × 4 depths) each AEZ of Bangladesh. Four depths of soil were considered (0-5, 5-10, 10-15 and 15-20 cm) for each sampling site. Soils samples were analyzed to find out the bulk density, organic carbon content and its storage in different depths with different land types irrespective of different AEZs. Soil bulk density (BD) for a specific depth in different land types and AEZ was calculated using the following equation:

$$\rho_b\ (\text{g cm}^{-3}) = \frac{\text{Core soil dry weight (g)}}{\text{Volume of core (cm}^3\text{)}}$$

where ρ_b is bulk density (g cm^{-3}). Soil organic carbon (SOC) stock for a specific depth in different land types and AEZs was calculated using the following equation Ussiri and Lal (2013):

$$\text{SOC (g ha}^{-1}) = \frac{\text{SOC (\%)}}{100} \times \rho_b \times \text{d cm} \times \frac{10^8 \text{ cm}^2}{\text{ha}}$$

where ρ_b is bulk density (g cm^{-3}) of the soil layer and d is soil depth in cm.

9.2. Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition without crop

Incubation study was carried out in the Laboratory of Soil Science, BINA to evaluate the effects of different organic residues and water regimes on carbon stock as well as decomposition constant in soil. Soil samples were collected from surface horizon (0–15 cm) using soil auger. The initial soil texture was sandy loam having pH 7.3, organic carbon 9.2 g kg^{-1}, 0.5 mol L^{-1} $NaHCO_3$-extractable P 95 ppm and 1 mol L^{-1} NH_4OAc-extractable K 24 ppm or 0.61 meq 100^{-1} g soil and C:N ration 11.5. Soil bulk density was measured using core sampler and it was 1.28 g cm^{-3}. Rice straw and rice root were collected from rice field after grain harvest. Then it was washed with distilled water and dried at 70°C in laboratory. Rice straw, rice root, cowdung and poultry litter C contents were 48.90, 42.20, 17.43 and 47.41% and total N, P and K contents were 0.63, 0.40, 1.04 and 1.00; 0.08, 0.29, 0.82 and 0.69; 2.35, 0.34, 0.68, 0.95%, respectively. C:N ratio were 77.61, 105.5, 16.75 and 47.41 in rice straw, rice root, cowdung and poultry litter, respectively. Straw and root were cut into small pieces (<1 cm), ground and mixed with soil samples for incubation study. Factorial experiment was laid out in a complete randomized design with 10 treatments, replicated five times. Rice straw, rice root, cowdung and poultry litter including control where no use of organic residues were tested under two water levels i.e. moistened condition: field capacity (MC) and flooding condition -2 cm water level (FC) systems. One jar was without organic residue and soil i.e. absolute control. Organic residues were thoroughly mixed with soil then transferred into air tight PVC pots for an equivalent of 200 g soil to 0.25 g C (5 t C ha^{-1}) per pot. Samples were wetted slowly with calculated amount of deionized water to maintain designed water level. 75 mL beaker contained 25 mL of 0.05 N NaOH solution and it was placed on soil surface inside the air tight pot to absorb carbon dioxide. Pots were covered with polyethylene sheet and incubated in the darkness at 25°C for 120 days. Excess NaOH was titrated with 0.05 N HCl after precipitating carbonates with $BaCl_2$ using phenolphthalein as indicator and subtracted from the amount of titrated in absolute control. All the pots were taken out and opened periodically, aerated for a few minutes and soil water content was checked and adjusted by weighing then adding distilled water to maintain water levels. The CO_2–C emission was measured at 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91, 98, 105, 112 and 120th day of incubation. The amount of CO_2-C was calculated using standard method.

A simple model was used to predict the rate of carbon change in soil is shown the equation.

$$C_t = C_0\ (1-e^{-kt})$$

Where k is the decomposition constant, C_0 is the potentially mineralizable carbon and C_t is the carbon mineralization in time t.

9.3. Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition with rice

Pot experiment was conducted at Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh to determine carbon stock, soil reaction and crop productivity during 2010-2011. Experimental soil was collected from AEZ 9: Old Brahmaputra Floodplain of BAU farm at Mymensingh. The initial soil texture was sandy loam having pH 7.3, organic carbon 9.2 g kg^{-1}, 0.5 mol L^{-1} $NaHCO_3$-extractable P 95 ppm and 1 mol L^{-1} NH_4OAc-extractable K 24 ppm or 0.61 meq 100^{-1} g soil and C:N ration was 11.5. Soil bulk density was measured using core sampler and it was 1.28 g cm^{-3}. Rice straw, rice root, cowdung and poultry litter with five levels of carbon (0.0, 0.5, 1.0, 1.5 and 2.0 t ha^{-1}) were tested using alternate wetting and drying (AWD) and continuous flooding (CF) conditions. Earthen pots with 27 cm × 28 cm sized were used for this experiment. Each pot was filled 8 kg of bulk soils. Experiment was laid out in a complete randomized design with three replications. After preparation of pot soils, 25 days old seedlings for BINAdhan 7 and 30 days old seedlings for BRRI dhan29 were transplanted. Each pot contained three hills followed by 2 seedlings per hill. Soil organic carbon and pH were estimated at 30, 60, 90, 120, 150, 180 and 360 days interval from starting point of this experiment. Grain and straw yields were recorded at maturity stage. Organic carbon and soil reaction were determined using the standard methods (Page *et al.*, 1982).

9.4. Carbon accumulation efficiency in soil using C_3 and C_4 crop residues

Incubation study was conducted at Soil Science Laboratory, Bangladesh Institute of Nuclear Agriculture, Mymensingh to determine the decomposition trend of C_3 (rice) and C_4 (sugarcane) crop residues. Experiment was laid out in a complete randomized design with three replications. Fresh rice straw (RS) and sugarcane straw (SS) with five levels of carbon (0.00, 0.48, 0.96, 1.44 and 1.92 t C ha^{-1}) mixed with soil were tested using field capacity (W_1) and continuous flooding (W_2) conditions. Eight kilogram (8 kg) soil was used for each air tight pot. CO_2-C emission was estimated 3 days interval from starting point of this experiment. The amount of CO_2-C was calculated following the standard method.

9.5. Carbon sequestration in soils under different tillage, crop establishment method and rice straw management

Field experiment was conducted at BINA substation, Ishurdi to determine the effects of different tillage methods and rice straw management practices on carbon emission, soil carbon content and yield of rice in five crop seasons during 2010-2012. Initial soil samples were collected for the determination of pH, SOC and N, P and K contents. The studied initial soil was silt loam having pH 7.26, organic carbon 9.8 g kg^{-1}, total nitrogen 0.11%, 0.5 mol L^{-1} $NaHCO_3$-extractable P 193 ppm and 1 mol L^{-1} NH_4OAc-extractable K 95 ppm or 2.43 meq 100^{-1} g soil and C:N ration was 11.5. Carbon content in rice straw was 51.44 and total N, P and K contents were 0.29, 0.07 and 2.39%, respectively. C:N ration was 177.35. Factorial experiment was laid out in a randomized complete block design with 6 treatment combinations, replicated four times. Fresh rice straw management practices (incorporation and mulch including control where no use of crop residue) were tested under two tillage systems i.e. traditional tillage (TT) and minimum tillage (MT) methods. Binadhan 7 in T.aman season and BRRI dhan29 in Boro season were used as the test variety. Supplement chemical fertilizers were used in rice straw treated plots and recommended doses of chemical fertilizers (RDF) were applied in control where rice straw was not applied. Rice straw at the rate of 5 t ha^{-1} was used as organic residue in each crop rotation. CO_2-C emission was measured at 10, 30, 60, 90, 120 and 150^{th} day after transplanting of rice. Reading was taken by every 15 days interval except 10 days and it was continued throughout the crop growing season. CO_2-C gas trapping system was followed according the procedure of experiment no. 2. Grain and straw yields were recorded at maturity stage. Soil carbon and nutrients were analyzed using standard methods.

9.6. Effect of different organic manures/residues and fertilizer management on carbon sequestration under rice-rice cropping pattern

A field experiment was conducted at the experimental farm of Bangladesh Institute of Nuclear Agriculture, Mymensingh during 2010-2012. Initial soil sample was taken from surface (0-15 cm) soil for the determination of soil physico-chemical properties. The initial soil of the experimental field was sandy loam having pH 6.50, organic carbon 8.4 g kg^{-1}, total nitrogen 0.08%, 0.5 mol L^{-1} $NaHCO_3$-extractable P 50 ppm and 1 mol L^{-1} NH_4OAc-extractable K 28 ppm or 0.72 meq 100^{-1} g soil. Bulk density of 0-15 cm soil layer measured using core sampler and it was 1.28 g cm^{-3}. N-P-K contents were 0.63-1.04-1.00; 0.08-0.82-0.69; 2.35-0.68-0.95 per cent in rice straw, cowdung and poultry manure, respectively. Five treatment combinations were integrated plant nutrient systems using rice straw (RS), cowdung (CD) and poultry manure (PM)/poultry likes (PL)

including control and Soil test based fertilizers (STB). The treatments were replicated four times with a plot size of 4 by 4 m^2. Transplanting of rice varieties (cultivars Binadhan-7 and BRRI dhan29) was done manually. After final preparation of land, 25 days old seedlings for Bina dhan7 and 30 days old seedlings for BRRI dhan29 were transplanted at 15 cm × 20 cm inter row spacing. Irrigation was applied to maintain a 4 cm depth of standing water during entire growth period of crop. Grain and straw yields were recorded at maturity stage and oven-dried at 70°C to record dry matter yield. After 5^{th} crop season, soil samples were collected from each subplot within 10 d after crop harvest from 0-15 cm soil depth using a 5 cm diameter auger. Each sample was a composite from three locations in a subplot. Organic carbon, total N, available P and exchangeable K were determined following the standard procedures. CO_2-C gas trapping system was followed according to the procedure of experiment no. 2. The amount of CO_2-C was calculated using the standard method.

Fertilizers application, methods of soil carbon, nutrients & carbon dioxide estimation and statistical analysis:

In experiment 9 (5 & 6), Binadhan-7 (T. aman season) and BRRI dhan29 (Boro season), nitrogen at the rate of 105 and 164 kg ha^{-1} was applied through urea, half at 15 days after transplanting and the remaining half at maximum tillering stage, respectively. A basal dose of 15, 24 and 11 kg ha^{-1} P, K and S for Binadhan-7 and 30, 96, 12 and 1 kg ha^{-1} P, K, S and Zn for BRRI dhan29, respectively was applied through triple super phosphate, muriate of potash, gypsum and zinc powder. Harvested plants were dried and ground by using a stainless steel mill. For P and K analysis were followed by tri-acid (HNO_3-$HClO_4$-H_2SO_4) mixture. One gram ground plant material was placed in 100 ml volumetric flask. To this, 10 ml of acid mixture was added and the content of the flask was mixed by swirling. The flask was placed on low heat hot plate in digestion chamber. Then the flask was heated at high temperature until the production of red NO_2 fumes ceased. The contents were further evaporated until the volume was reduced to about 3 to 5 ml but not to dryness. The completion of digestion was confirmed when the liquid become colorless. After cooling the flask, add 20 ml of distilled water. Volume was made up with distilled water and the solution was filtered through Whatman no. 42 filter paper. Phosphorus and potassium in grain and straw aliquots were analyzed by standard method. Total N was analyzed by micro-Kjeldhal method. The digested samples were transferred to a 100 ml volumetric flask and diluted with distilled water up to the mark and filtered through Whatman no 42. Ten ml of the digest was taken and transferred to vacuum jacket of micro-Kjeldhal distillation apparatus. After completion of distillation, the boric acid was titrated against H_2SO_4 acid. For soil analysis, coarse concretions, stones and pieces of

roots, leaves and other undecomposed organic residues were removed. The soil was air dried ground, sieved through 2 mm sieve and kept in plastic bags for physico-chemical analysis. Soil pH, organic carbon, total N, available phosphorus, exchangeable K measured by glass electrode pH meter method, wet oxidation method, micro-Kjeldahl method, Olsen method and flame photometer on the neutral ammonium acetate extract solution, respectively. Wet-oxidation method was used for the analysis of organic carbon and the organic matter was calculated by multiplying the organic carbon by Van Bemmelen factor, 1.73. During field experimentation, greenhouse gas CO_2–C was determined by titrimetric method using HCl, NaOH and $BaCl_2$ chemicals.

The amount of CO_2-C was calculated by using the formula.

$$\text{mg evolved } CO_2\text{/day} = \frac{(T_2-T_1)\ M \times 22}{t}$$

where, T_1 = amount of HCl used to neutralize NaOH, $T_2 = T_1$ + amount of HCl used to dissolve precipited $BaCO_3$, M = molarity of HCl, 22 = 22 mg CO_2/1ml 1M HCL, t = time in days. The CO_2-C in the control treatment was substracted from the calculated value for CO_2-C release. The difference among the parameter means was judged by standard error value (SE±) in respect of carbon status in different AEZs of Bangladesh. The recorded data were analyzed using one/two way analysis of variance (ANOVA) by the statistical package MSTA-C program and means following least significant difference (LSD) test at 5% level of probability for the interpretation of results.

10. Results and Discussion

10.1. Assessment of existing carbon stocks in soils of 10 AEZs in Bangladesh

Bulk density and organic carbon content results are presented in Table 1 in respect of different land types and depths of AEZs 11 – 12 soils. The highest bulk density was found in AEZ 12. Minimum bulk density was observed 0.67, 0.76, 0.73 and 0.69 g cm^{-3} in 0-5, 5-10, 10-15 and 15-20 cm at AEZ 14, respectively. At 0-5 cm soil depth, bulk density was decreased in the order of HL<MHL<MLL<LL<VLL in soil except AEZ 17 and 18. Based on the results, it may be concluded that bulk density is increased with the increase of soil depth at different AEZs of Bangladesh. Organic carbon content was more in lower bulk density than higher bulk density containing soil. The highest organic carbon content was observed in 0- 5 cm depth in all AEZs except AEZ 14 and the lowest organic carbon was found in 15-20 cm depth of soil. SOC content (%) in highland was medium in AEZ 11, 12, 13, 18 & 19 and very low in AEZ 16 and 17, as per soil organic carbon ranking in Fertilizer Recommendation Guide (BARC, 2005). Organic carbon content in very

lowland soil was very high in AEZ 14 and 15. From the study, it was clear that organic carbon content gradually decreased with the increase of soil depth. This finding is agreed with the results of Hossain and Sattar (2002).

Depth and land type wise soil organic carbon stock results are presented (Table 2). Maximum organic carbon stock (74.50 t ha^{-1}) was obtained from 10 – 15 cm depth in AEZ 14. Among the AEZs, AEZ 16, 17 and 18 contained minimum organic carbon in soil compared to other studied AEZs. According to land type, the range of soil organic carbon stock in AEZ 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20 was 6.57-11.06, 9.31-33.49, 8.29-9.37, 17.68-69.61, 22.23-34.87, 3.55-8.30, 3.93-5.23, 5.10-6.63, 9.23-11.84 and 5.08-8.52 t ha^{-1}, respectively. The highest SOC stock was observed in surface soil (0 – 5 cm) and the lowest SOC stock was found in 15- 20 cm soil depth. It appeared that SOC stock decreased gradually with the increase of soil depth irrespective of land types. Lowland and very lowland soils contained higher organic carbon content than other land types. Higher amount of SOC in lowland and very lowland soil might be due to very slow decomposition of organic residues (Iqbal *et al.,* 2009).

Organic carbon content and stocks results in respect of land type in different AEZs are summarized (Table 3). Highest organic carbon content was found in very lowland soil in AEZ 12, 14, 16, 19 and 20. The lowest organic carbon content was found in highland soil in all AEZs. Maximum organic carbon stock (1.40 million tones) was observed in AEZ 13 and the lowest organic carbon stock (0.01 million tonnes) was found in AEZ 15 irrespective of AEZ basis. Soil organic carbon stock was increased in the order of VLL>LL>MLL>MHL>HL in soil in different AEZs. Soil organic carbon stock was observed in the order of AEZ 13>11>12>19>18>20>14>16>17>15.

The tendency of carbon density increase with the decrease of altitude means sea level from the studied AEZs may be due to better stabilization of SOC at lowland and very lowland soils in Bangladesh because lowland remained submerged condition most of the time of the year. As a result, waterlogged condition helps to create anaerobic condition (Iqbal *et al*., 2009). Maximum organic carbon content was in 0-5 cm soil depth and it was decreased with increase of depth. Crop grows on surface soil and most of the crop residue remains in surface soil. So, cropping pattern should introduce with different rooting depth crops for increasing carbon content in different depth of soils. Higher organic carbon content was found in lowland and very lowland soils than high and medium highland soils. From these results it may be concluded that organic carbon content reduced by oxidation process in high and medium highland soil due to intensive crop cultivation. High and medium highland soils also easily expose to oxygen of atmosphere and it enhances soil organic carbon decomposition (Kong *et al*., 2005).

Table 1. Land type and area, bulk density (g cm^{-3}) and organic carbon content (%) at different depths of soils in different AEZs of Bangladesh

AEZ	Area, land type and coverage			Bulk density in different depths (cm)				Organic carbon in different depths (cm)			
	(ha)	LT	(%)	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20
11	1320549	HL	43	1.30±0.015	1.31±0.016	1.39±0.021	1.54±0.019	1.14±0.119	1.06±0.118	0.74±0.077	0.77±0.117
		MHL	32	1.28±0.031	1.32±0.027	1.42±0.030	1.59±0.024	1.67±0.267	1.37±0.171	1.15±0.205	0.94±0.127
		MLL	12	1.23±0.031	1.32±0.046	1.43±0.050	1.55±0.026	1.95±0.218	1.46±0.229	1.07±0.225	1.03±0.126
		LL	2	1.12±0.155	1.07±0.105	1.19±0.235	1.26±0.285	2.40±0.290	2.36±0.210	1.76±0.625	1.58±0.640
12	796851	HL	13	1.39±0.029	1.43±0.045	1.41±0.067	1.64±0.048	1.66±0.135	1.48±0.101	1.25±0.152	0.76±0.205
		MHL	29	1.32±0.035	1.32±0.026	1.38±0.028	1.56±0.031	2.42±0.217	2.30±0.250	1.76±0.211	1.14±0.193
		MLL	31	1.23±0.050	1.30±0.045	1.33±0.005	1.51±0.060	3.23±0.155	2.67±0.080	2.81±0.840	2.88±1.075
		LL	14	1.21±0.012	1.26±0.017	1.35±0.023	1.56±0.029	4.03±0.011	2.27±0.058	2.40±0.023	2.28±0.035
		VLL	2	1.08±0.011	1.26±0.018	1.33±0.012	1.39±0.040	7.90±0.231	6.85±0.375	4.49±0.167	2.68±0.116
13	1706573	HL	2	1.30±0.021	1.37±0.019	1.46±0.020	1.50±0.019	1.48±0.121	1.41±0.112	1.05±0.107	0.90±0.111
		MHL	78	1.25±0.033	1.30±0.027	1.47±0.040	1.50±0.028	1.86±0.183	1.67±0.198	1.00±0.138	0.73±0.099
		MLL	2	1.33±0.027	1.52±0.031	1.52±0.016	1.48±0.036	1.41±0.134	1.83±0.649	0.86±0.091	1.03±0.155
14	224700	HL	3	1.25±0.012	1.19±0.040	1.29±0.023	1.50±0.023	2.73±0.017	2.60±0.058	2.52±0.058	2.81±0.066
		MHL	13	1.21±0.015	1.21±0.012	1.22±0.019	1.12±0.098	5.46±0.294	5.95±0.416	5.93±0.185	7.11±0.352
		MLL	41	1.02±0.040	1.05±0.052	1.11±0.029	1.19±0.017	9.38±0.185	9.58±0.577	8.15±0.067	8.40±0.546
		LL	28	0.91±0.028	0.92±0.023	0.92±0.011	0.95±0.017	12.60±0.635	15.87±0.207	14.50±1.131	12.64±0.814
		VLL	11	0.67±0.063	0.76±0.057	0.73±0.046	0.69±0.040	21.90±1.293	20.51±1.784	20.41±1.258	15.17±0.542
15	14436	MLL	13	1.36±0.058	1.51±0.092	1.45±0.040	1.60±0.098	5.00±0.017	3.63±0.020	2.45±0.075	1.22±0.075
		LL	73	1.16±0.040	1.23±0.069	1.35±0.080	1.47±0.069	7.56±0.912	6.14±0.121	4.90±0.191	3.37±0.109

AEZ = Agroecological zone, LT = Land type, HL = Highland, MHL = Medium highland, MLL = Medium lowland, LL = Lowland and VLL = Very lowland and SE (±) = standard error

Table 1. Contd.

AEZ	Area, land type and coverage			Bulk density in different depths (cm)				Organic carbon in different depths (cm)			
	(ha)	LT	(%)	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20
16	155464	MHL	8	1.25±0.021	1.34±0.027	1.42±0.016	1.43±0.054	0.81±0.197	0.64±0.087	0.40±0.049	0.33±0.044
		MLL	29	1.26±0.067	1.33±0.057	1.40±0.038	1.47±0.050	0.50±0.115	0.26±0.095	0.24±0.044	0.57±0.115
		LL	25	1.14±0.035	1.31±0.051	1.38±0.029	1.26±0.115	1.18±0.149	1.09±0.133	0.50±0.093	0.79±0.370
		VLL	11	1.16±0.100	1.18±0.080	1.24±0.077	1.32±0.056	2.24±0.330	2.26±0.350	1.15±0.305	0.74±0.040
17	90934	HL	14	1.15±0.046	1.28±0.028	1.45±0.019	1.48±0.016	1.07±0.119	0.74±0.120	0.38±0.079	0.31±0.072
		MHL	28	1.19±0.035	1.24±0.037	1.37±0.037	1.44±0.031	1.12±0.082	0.87±0.084	0.64±0.063	0.32±0.036
		MLL	31	1.16±0.028	1.14±0.033	1.34±0.039	1.44±0.040	1.32±0.114	1.04±0.118	0.73±0.111	0.47±0.100
18	926885	MHL	45	1.10±0.031	1.23±0.029	1.42±0.019	1.45±0.012	1.46±0.054	1.12±0.042	0.50±0.027	0.33±0.015
		MLL	7	1.18±0.032	1.27±0.062	1.41±0.012	1.52±0.048	0.94±0.115	1.13±0.041	1.39±0.516	0.55±0.075
19	774026	HL	2	1.27±0.026	1.25±0.029	1.40±0.031	1.46±0.023	1.62±0.172	1.67±0.171	1.21±0.103	1.10±0.153
		MHL	24	1.10±0.047	1.21±0.043	1.40±0.050	1.44±0.031	2.89±0.257	2.48±0.391	1.57±0.335	0.98±0.141
		MLL	33	1.09±0.041	1.15±0.064	1.26±0.065	1.34±0.070	2.13±0.247	1.84±0.282	1.39±0.268	1.28±0.253
		LL	21	1.03±0.026	1.18±0.059	1.33±0.037	1.44±0.015	2.43±0.286	1.94±0.338	1.34±0.333	1.15±0.329
		VLL	3	0.90±0.034	1.09±0.046	1.16±0.031	1.24±0.018	2.39±0.277	2.04±0.322	1.41±0.355	0.93±0.358
20	462159	HL	5	1.18±0.034	1.02±0.066	1.22±0.062	1.52±0.030	1.16±0.149	1.03±0.123	0.72±0.132	0.58±0.200
		MHL	25	1.18±0.044	1.12±0.052	1.31±0.059	1.37±0.071	1.11±0.136	0.95±0.152	0.66±0.107	0.94±0.195
		MLL	20	0.96±0.061	1.10±0.045	1.18±0.077	1.17±0.066	1.95±0.302	1.32±0.207	0.94±0.212	1.22±0.259
		LL	36	1.00±0.061	0.99±0.064	1.09±0.057	1.15±0.044	1.68±0.232	1.97±0.308	1.77±0.237	1.50±0.235

AEZ = Agroecological zone, LT = Land type, HL = Highland, MHL = Medium highland, MLL = Medium lowland, LL = Lowland and VLL = Very lowland and SE (±) = standard error

Table 2. Land type and area, organic carbon stock (t ha^{-1}) at different depths (cm) of soils in different AEZs of Bangladesh

AEZ	Area, land type and coverage			Organic carbon stock in different depths (t ha^{-1})			
	(ha)	LT	(%)	0-5	5-10	10-15	15-20
11	1320549	HL	43	7.83±0.841	7.16±0.775	5.20±0.496	6.09±0.920
		MHL	32	10.02±1.732	8.91±1.055	8.00±1.382	7.44±1.009
		MLL	12	11.87±1.154	9.37±1.227	7.44±1.439	7.91±0.923
		LL	2	13.15±0.235	12.41±0.115	9.69±1.645	8.99±1.775
12	796851	HL	13	11.59±1.035	10.86±0.735	8.76±1.003	6.02±1.556
		MHL	29	15.76±1.232	15.09±1.519	12.02±1.221	8.56±1.205
		MLL	31	20.32±0.275	17.83±0.795	18.76±4.230	21.73±5.290
		LL	14	23.98±0.057	14.15±0.574	16.15±1.126	17.74±0.748
		VLL	2	42.66±1.813	43.16±1.097	29.51±0.548	18.63±1.183
13	1706573	HL	2	9.42±0.069	9.44±0.673	7.50±0.726	6.81±0.772
		MHL	78	11.59±1.114	10.83±1.246	7.20±0.963	5.42±0.661
		MLL	2	9.41±0.095	13.94±2.117	6.53±0.725	7.60±1.029
14	224700	HL	3	17.06±1.154	15.47±1.527	16.25±0.882	21.92±0.577
		MHL	13	33.03±0.577	36.00±1.333	36.17±0.433	39.82±1.154
		MLL	41	47.84±1.527	50.30±1.327	45.23±1.154	49.98±1.453
		LL	28	57.42±1.847	73.00±0.635	66.70±0.692	60.04±1.160
		VLL	11	73.67±1.733	77.94±1.362	74.50±1.293	52.34±1.091
15	14436	MLL	13	34.00±0.641	27.41±1.125	17.76±1.963	9.76±0.271
		LL	73	43.85±0.814	37.76±1.656	33.08±2.211	24.77±0.843
16	155464	MHL	8	5.00±1.243	4.13±0.554	2.74±0.337	2.35±0.335
		MLL	29	2.72±0.057	1.67±0.425	1.53±0.277	0.46±0.360
		LL	25	6.81±0.972	7.14±0.924	3.37±0.641	2.81±0.806
		VLL	11	10.44±0.280	11.21±0.335	6.76±0.838	4.80±0.590
17	90934	HL	14	6.22±0.622	4.51±0.665	2.69±0.536	2.31±0.430
		MHL	28	6.57±0.496	5.29±0.451	4.51±1.189	2.32±0.239
		MLL	31	7.39±0.537	5.72±0.540	4.67±0.567	3.14±0.520
18	926885	MHL	45	7.81±0.324	6.75±0.281	3.51±0.204	2.32±0.129
		MLL	7	5.38±0.525	7.20±0.332	9.87±1.673	4.06±0.380
19	774026	HL	2	10.12±1.014	10.35±1.081	8.38±0.677	8.05±1.115
		MHL	24	15.68±1.461	14.18±2.048	10.46±2.247	7.04±1.085
		MLL	33	11.25±1.422	9.96±1.321	8.01±1.249	7.89±1.361
		LL	21	12.84±1.509	11.45±1.917	9.63±2.089	6.62±1.984
		VLL	3	9.87±1.437	9.64±1.571	6.44±1.535	3.61±0.959
20	462159	HL	5	6.71±0.715	5.03±0.443	4.11±0.576	4.45±1.594
		MHL	25	6.29±0.576	5.03±0.600	3.97±0.524	5.60±0.888
		MLL	20	8.92±1.111	6.96±0.950	5.04±0.852	6.55±1.165
		LL	36	8.87±0.856	8.61±1.087	8.49±1.131	8.11±1.130

AEZ = Agroecological zone, LT = Land type, HL = Highland, MHL = Medium highland, MLL = Medium lowland LL = Lowland and VLL = Very lowland and SE (±) = standard error

Table 3. Organic carbon content (%), organic carbon stock (t ha^{-1}) at different land types and carbon stock (million tonnes per AEZ) in different AEZs of Bangladesh

AEZ/ LT	Organic carbon content (%)					Organic carbon stock (t ha^{-1})					C stock (AEZ)
	HL	MHL	MLL	LL	VLL	HL	MHL	MLL	LL	VLL	(t $\times 10^6$)
11	0.93±0.101	1.28±0.156	1.38±0.214	2.03±0.208	-	6.57±0.580	8.59±0.564	9.15±0.996	11.06±1.015	-	1.18±0.123
12	1.29±0.195	1.91±0.293	2.90±0.119	2.75±0.429	5.48±1.174	9.31±1.249	12.86±1.648	19.66±0.860	18.01±2.123	33.49±5.875	0.71±0.043
13	1.21±0.139	1.32±0.268	1.28±0.216	-	-	8.29±0.672	8.76±1.469	9.37±1.635	-	-	1.40±0.432
14	2.67±0.065	6.11±0.351	8.88±0.354	13.90±0.792	19.50±1.482	17.68±1.452	36.26±1.389	48.34±1.171	64.29±3.499	69.61±5.831	0.22±0.015
15	-	-	3.08±0.809	5.49±0.892	-	-	-	22.23±5.329	34.87±4.023	-	0.01±0.004
16	-	0.55±0.111	0.39±0.084	0.89±0.154	1.60±0.386	-	3.55±0.615	1.60±0.462	5.03±1.129	8.30±1.518	0.11±0.008
17	0.63±0.176	0.74±0.170	0.89±0.185	-	-	3.93±0.901	4.67±0.892	5.23±0.894	-	-	0.07±0.005
18	-	0.85±0.264	1.00±0.177	-	-	-	5.10±1.301	6.63±1.258	-	-	0.48±0.176
19	1.40±0.144	1.98±0.433	1.66±0.198	1.72±0.292	1.69±0.325	9.23±0.589	11.84±1.940	9.28±0.811	10.14±1.343	7.39±1.483	0.64±0.047
20	0.87±0.134	0.92±0.093	1.36±0.213	1.73±0.098	-	5.08±0.577	5.22±0.490	6.87±0.799	8.52±0.158	-	0.40±0.030

AEZ = Agroecological zone, LT = Land type, HL = Highland, MHL = Medium highland, MLL = Medium lowland, LL = Lowland and VLL = Very lowland and SE (±) = standard error

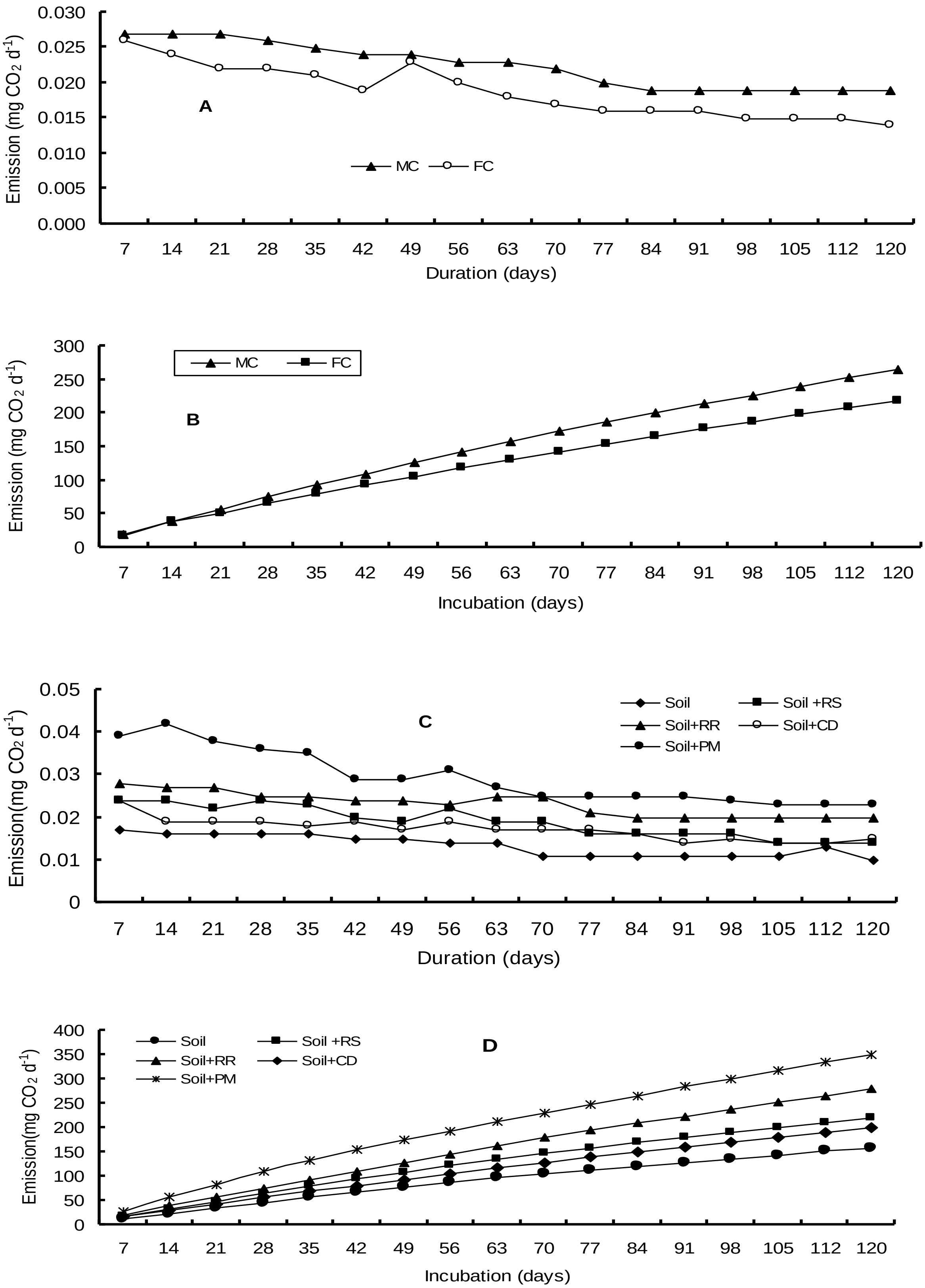
10.2. Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition without crop

Effect of water levels on carbon dioxide emission rate and cumulative CO_2-C results are presented (Graph A & B). Carbon dioxide emission results were statistically significant at all the studied durations except 7 and 49th day. Maximum carbon dioxide emission (0.027 and 0.026 mg d^{-1} g^{-1} soil) was found at 7 days after incubation in moistened and flooding conditions respectively than it was decreased with the increase of time except 49th day after incubation. Total carbon dioxide emission was observed 265.45 and 218.28 mg CO_2-C in moistened and flooding conditions at 120 days after incubation. Total input and output carbon, uncounted carbon and carbon degradation constant results are presented (Table 4). Soil and organic residue contributed 0.92 and 0.20 g C per pot, respectively. Maximum carbon (0.072 g) emission was found in moistened condition and the minimum carbon (0.058 g) emission was observed in continuous flooding condition. Maximum residual carbon (1.032 g) was achieved in flooding condition and the lowest carbon (1.012 g) was found in moistened condition. Higher uncounted carbon balance (0.036 g) was found in moistened condition. Maximum carbon degradation rate (0.007 g C d^{-1}) was obtained from moistened condition due to higher oxidation process. Moistened condition enhanced the oxidation process of organic residues during incubation periods. Carbon degradation rate was lower in anaerobic condition than aerobic condition. The cumulative CO_2-C production was significantly decreased with the increase moisture levels (moistened>flooding system) for the entire incubation period. Flooding condition yielded more SOC than moistened condition.

Effect of organic residues on carbon dioxide emission rate is presented (Graph C). Organic residue with mixture of soil was significantly increased carbon dioxide emission over soil alone. Poultry litter produced the highest CO_2-C evolution from 7 to 120 days of incubation. Control treatment performed the lowest CO_2-C emission during entire period of incubation study. Maximum carbon dioxide emission (0.042 mg d^{-1} g^{-1} soil) was found in poultry litter mixed soil at 14 days after incubation and the lowest carbon dioxide emission (0.017 mg d^{-1} g^{-1} soil) was found in only soil treated pot. Cumulative CO_2-C evolution was increased with the increase of time (Graph D). Mixing of organic residues with soil significantly increased cumulative CO_2-C. Incorporation of crop residues provides a source of readily available C and subsequently influences the CO_2-C emission (Lemke et al., 1999). It brought roughly a 121% increase in cumulative CO_2-C production in poultry litter treated pot compared to control. The percent of carbon mineralized 39.21, 77.13, 42.14 and 114.82 from rice straw, rice root, cowdung and poultry litter, respectively over control. The CO_2-C emission trend was increased in the order of poultry litter>rice root>rice straw>cowdung. Total input and output carbon, uncounted carbon and carbon degradation constant rate results are presented (Table 5). Higher carbon

emission (0.095 g) was found in poultry litter treated pot and the lowest carbon emission (0.040 g) was observed in soil treated pot. The amount of soil retained carbon was 1.060g and emission C was 0.095g poultry manure with soil mixture (Table 5). Maximum apparent carbon balance (1.16 g) was achieved in cowdung treated pot and the lowest carbon content was found in soil treated pot. Higher uncounted carbon was found in soil + rice root treatment. There were significant differences in the *k* value of organic residues (Table 5). The *k* values of rice straw, rice root, cowdung, poultry litter and soil alone were 0.003, 0.005, 0.005, 0.008 and 0.008g C per day, respectively. Incorporation of crop residues provides a source of readily available C and subsequently influences the CO_2-C emission. The residue type was thought to be an important factor affecting CO_2-C emission. Decrease in residue mineralization in later stages may be indicated that more organic carbon was sequestered in soil or was incorporated into microbial biomass. Degradation constant (k) value is good indicator to select effective carbon sequester in soil and reduce environmental pollution.

Interaction results revealed that mixing of organic residues with soil and different levels of water significantly affected rate and cumulative CO_2-C emission, apparent carbon balance, uncounted carbon and decomposition constant rate of organic residues (Table 4). MC × Soil increased 13% carbon emission over FC × soil. FC × soil + poultry litter treated pot produced 100% more CO_2-C over FC × Soil. Organic residues in combination with water level produced the maximum CO_2-C rate and cumulative CO_2-C over soil alone with water level. Maximum residue organic carbon content (1.11g) was observed in FC × soil + rice straw and FC × soil + cowdung treated pot (Table 5). The lowest residue organic carbon content was found in FC × soil. Lowest uncounted carbon was found in FC × soil. Maximum k value was found in soil alone irrespective of water levels. The cumulative CO_2-C production was significantly decreased with increasing moisture levels (moistened > flooding system) for the entire incubation period. This finding may rule out negative influence of flooding condition on microbial activity due to anaerobic conditions. Researchers reported that mineralization of organic residues highly depended on water levels of soil in incubation (Tulina *et al.*, 2009). Highest k value was found in MC × Soil + RR whereas FC × Soil + RR produced the least carbon degradation in soil due to anaerobic condition. Different organic residues with different water levels showed different decomposition constant rate due to some reasons. Firstly, decomposition rate depends on C:N ratio of the tested materials. A high C:N ratio containing organic residue slows the rate of residue breakdown because lignin content was higher than other easily decomposable compounds. From this result, it may be concluded that arable land without vegetation increased CO_2-C emission through oxidation process for enhancing environmental pollution. Based on these discussions, organic residues along with flooding condition improved soil organic carbon and reduced environmental pollution.



Graph 1. Rate and cumulative CO_2-C emission: (A & B) rate and cumulative CO_2–C at different water levels; (C & D) rate and cumulative CO_2–C at different organic residues, respectively

Table 4. Interaction effect of organic residues and water levels on carbon dioxide carbon emission

Treatment	Incubation period (days)																
	7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**	**98**	**105**	**112**	**120**
	---------- CO_2-C emission (mg g^{-1} soil) ----------																
Carbon emission																	
MC×Soil	0.016	0.015	0.015	0.015	0.015	0.014	0.013	0.013	0.013	0.013	0.012	0.012	0.012	0.012	0.012	0.016	0.012
MC×Soil+RS	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023	0.022	0.022	0.016	0.016	0.016	0.016	0.016	0.016	0.016
MC×Soil+RR	0.030	0.030	0.030	0.030	0.029	0.027	0.028	0.029	0.029	0.029	0.023	0.022	0.022	0.022	0.022	0.022	0.022
MC×Soil+CD	0.022	0.018	0.018	0.018	0.018	0.017	0.018	0.017	0.017	0.017	0.017	0.014	0.014	0.015	0.014	0.014	0.015
MC×Soil+PM	0.042	0.050	0.047	0.043	0.041	0.037	0.036	0.034	0.034	0.030	0.030	0.030	0.030	0.030	0.029	0.029	0.028
FC ×Soil	0.018	0.017	0.017	0.017	0.016	0.016	0.097	0.016	0.016	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.009
FC ×Soil+RS	0.023	0.023	0.021	0.023	0.022	0.016	0.016	0.021	0.015	0.015	0.015	0.015	0.015	0.015	0.012	0.012	0.012
FC ×Soil+RR	0.026	0.025	0.024	0.021	0.022	0.021	0.021	0.017	0.021	0.021	0.019	0.019	0.019	0.019	0.019	0.019	0.019
FC ×Soil+CD	0.025	0.020	0.020	0.020	0.018	0.021	0.017	0.021	0.017	0.017	0.017	0.017	0.014	0.014	0.014	0.014	0.014
FC ×Soil+PM	0.036	0.034	0.030	0.030	0.029	0.021	0.021	0.027	0.021	0.021	0.021	0.021	0.021	0.019	0.018	0.018	0.018
$LSD_{0.05}$	NS	0.023	0.022	0.022	0.070	0.023	NS	0.022	0.023	0.007	0.023	0.022	NS	0.022	NS	NS	0.007
Cumalative carbon emission																	
MC×Soil	11.32	22.17	32.96	43.80	54.27	64.28	73.64	82.63	91.72	100.79	108.87	116.97	125.04	133.15	141.21	149.32	157.56
MC×Soil+RS	16.99	33.77	50.51	67.31	83.79	99.83	116.21	132.29	147.39	162.44	173.46	184.51	195.60	206.79	217.91	229.50	240.26
MC×Soil+RR	21.27	42.05	62.78	83.62	104.08	123.17	142.49	162.58	182.68	202.78	218.85	233.94	249.04	264.15	279.26	294.37	309.59
MC×Soil+CD	15.34	28.24	41.08	53.94	66.25	78.49	90.85	102.95	115.08	127.17	139.26	149.36	159.48	169.65	179.76	189.85	200.08
MC×Soil+PM	29.29	64.10	96.90	126.76	155.26	181.29	206.63	230.72	254.83	275.89	296.96	318.01	339.12	360.29	380.41	400.51	419.77
FC ×Soil	12.38	24.31	36.12	47.90	59.43	70.51	81.59	92.59	103.69	110.80	117.90	124.98	132.08	138.95	145.94	152.92	158.90
FC ×Soil+RS	16.24	32.10	46.87	62.62	78.14	89.10	99.96	110.58	121.20	131.82	142.44	153.05	163.69	174.37	182.97	191.58	200.29
FC ×Soil+RR	18.33	36.17	52.94	67.72	83.24	98.16	112.95	127.54	142.05	156.61	170.15	183.69	197.24	210.79	224.34	237.88	251.52
FC ×Soil+CD	17.32	31.23	45.00	58.79	71.35	83.24	94.99	106.55	118.13	129.69	141.25	152.81	162.37	171.93	181.47	191.03	200.65
FC ×Soil+PM	25.32	49.20	70.06	90.84	111.35	126.27	141.07	155.67	170.27	184.85	199.43	214.02	228.60	242.19	254.77	267.36	280.04
$LSD_{0.05}$	NS	7.24	6.71	5.45	6.49	5.22	7.11	4.79	8.27	7.07	11.20	13.58	8.15	7.72	8.13	9.43	1.01

Table 5. Carbon balance from different organic residues in 100 g soil

Treatment	Carbon input (g)			Carbon output (g)			Uncounted C (g)	Degradation rate: k (g d^{-1})
	Soil carbon	Residues carbon	Total carbon	Emission carbon	Residual carbon	Apparent C balance		
				Water levels (W)				
MC	0.92	0.20	1.12	0.072	1.012	1.084	0.036	0.007
FC	0.92	0.20	1.12	0.058	1.032	1.090	0.030	0.005
				Organic residues (OR)				
Soil	0.92	0.00	0.92	0.040	0.870	0.911	0.010	0.008
Soil + RS	0.92	0.25	1.17	0.060	1.050	1.109	0.061	0.003
Soil + RR	0.92	0.25	1.17	0.076	1.025	1.101	0.069	0.005
Soil + CD	0.92	0.25	1.17	0.054	1.105	1.160	0.011	0.005
Soil + PM	0.92	0.25	1.17	0.095	1.060	1.155	0.015	0.008
				Interaction (W×OR)				
MC × Soil	0.92	0.00	0.92	0.043	0.870	0.913	0.007	0.008
MC × Soil + RS	0.92	0.25	1.17	0.065	0.990	1.053	0.117	0.001
MC × Soil + RR	0.92	0.25	1.17	0.084	1.060	1.144	0.026	0.008
MC × Soil + CD	0.92	0.25	1.17	0.054	1.100	1.154	0.016	0.005
MC × Soil + PM	0.92	0.25	1.17	0.114	1.040	1.154	0.016	0.010
FC × Soil	0.92	0.00	0.92	0.038	0.870	0.908	0.012	0.008
FC × Soil + RS	0.92	0.25	1.17	0.055	1.110	1.165	0.005	0.004
FC × Soil + RR	0.92	0.25	1.17	0.068	0.990	1.058	0.112	0.001
FC × Soil + CD	0.92	0.25	1.17	0.055	1.110	1.165	0.005	0.004
FC × Soil + PM	0.92	0.25	1.17	0.076	1.080	1.156	0.014	0.007
$LSD_{0.05}$								
W	NS	NS	NS	0.013	NS	NS	0.005	0.002
OR	NS	0.016	0.072	0.016	0.143	0.113	0.016	0.005
W×OR	NS	NS	NS	NS	NS	NS	0.023	0.022

10.3. Carbon accumulation and its mineralization in soils under aerobic and anaerobic condition with rice

Effect of water management on organic carbon, pH and yield of rice are presented (Table 6-8). Maximum organic carbon content was found in continuous flooding condition at different durations except 30 days after transplanting (DAT) of rice. Among the soil sampling durations, highest organic carbon content (0.609%) was obtained from 60 DAT. Organic carbon content was higher in continuous flooding condition than alternate wetting and drying condition due to inhibition of the oxidation process of organic residues. Continuous flooding condition produced the maximum soil pH at different durations except 120 DAT. Higher pH results were observed in 30, 90 and 120 DAT than 60, 180 and 360 DAT. Continuous flooding condition showed the highest grain and straw yield than alternate wetting and drying in 2010 and 2011. BRRI dhan 29 produced higher grain yield than Bina dhan7 due to seasonal variation.

Effect of organic residues on organic carbon, pH and yield of rice results are presented (Table 6-8). Organic carbon content was not statistically significant except 60 and 360 DAT. Highest organic carbon content was observed in poultry manure and cowdung treated pots. At 60, 90 and 120 DAT, maximum organic carbon was found in poultry litter treated pots. Cowdung produced the highest organic carbon content at 360 DAT. Rice root produced the lowest organic carbon content in soil at 30 and 60 DAT. All the organic residues increased significant amount of carbon over the initial soil. Soil reaction was statistically significant in different organic residues treated pots. Among the organic residues, poultry manure treated pots produced the highest pH in soil. Soil pH significantly decreased after 180 and 360 DAT. Grain yield was not statistically significant in 2010. Grain and straw yield ranged from 11.79–12.61 and 14.22–17.07 g per hill in 2010. Highest grain (12.60 g per hill) and straw (17.07 g per hill) yield were observed in poultry manure treated pots and the lowest grain and straw yield were found in cowdung and rice root treated pots. In 2011, higher grain yield (21.16g per hill) was obtained from continuous flooding condition.

Effects of different doses of organic residues on organic carbon, pH and rice yield are presented (Table 6-8). Organic carbon content results were statistically significant except 30 DAT. Highest organic carbon content (0.619%) was found in 360 DAT. Organic carbon content increased with the increase of time. At 30 days after transplanting (DAT) of rice, lowest organic carbon was found in each organic material treated pots. Maximum organic carbon was found in 1.5 and 2.0 t C ha^{-1} treated pots. Each dose of organic residues was increased organic carbon over control. From these results it may be concluded that organic residues increased the accumulation of organic carbon in soil. Soil reaction was not statistically significant at 30, 60 and 90 DAT. Among the organic residues levels, 2.0 t C ha^{-1} produced the highest pH results in soil. Soil pH significantly decreased after 150, 180 and 360 DAT. In 2010, maximum grain and straw yield (16.49

and 20.20 g per hill) was observed in 2.0 t C ha^{-1} and minimum grain and straw yield (2.79 and 2.74 g per hill) was found in control treatment, respectively. Highest grain and straw yield was observed @ 2.0 t C ha^{-1} in 2011. Based on these results, it may be concluded that higher dose of organic residue supplied significant amount of plant nutrients during crop production.

Table 6. Effect of water and residues management practices on organic carbon status at different duration

Treatment	Duration (days)						
	30	60	90	120	150	180	360
	---------------------------- Organic carbon (%) -------------------------------						
Water regime							
AWD	0.529a	0.544	0.470	0.474b	0.471b	0.477b	0.572
FC	0.468b	0.609	0.486	0.538a	0.498a	0.578a	0.591
Sources of organic material							
Rice straw	0.476	0.536c	0.485	0.494	0.499	0.489	0.550b
Rice root	0.473	0.555c	0.466	0.455	0.463	0.447	0.533b
Cowdung	0.557	0.592b	0.475	0.506	0.478	0.534	0.585a
Poultry manure	0.488	0.622a	0.487	0.519	0.498	0.539	0.558ab
Doses of organic material (t C ha^{-1})							
0.0	0.475	0.541d	0.455c	0.455b	0.466b	0.445c	0.507b
0.5	0.483	0.546cd	0.460bc	0.507ab	0.459b	0.554ab	0.541b
1.0	0.517	0.578bc	0.491ab	0.494b	0.494ab	0.494bc	0.546b
1.5	0.520	0.610a	0.474bc	0.564a	0.514a	0.613a	0.594a
2.0	0.498	0.607ab	0.511a	0.511ab	0.490ab	0.531abc	0.619a
CV(%)	30.06	8.71	11.46	23.10	12.54	33.72	14.20

AWD-alternate wetting and drying, FC-flooding condition; the means in column bearing same letters do not differ significantly ($p<0.05$, NS-non-significant).

Table 7. Effect of water and residues management practices on pH at different duration

Treatment	Duration (days)						
	30	60	90	120	150	180	360
Water regime							
AWD	7.05b	6.94	7.30a	7.32a	6.79	6.56a	6.65a
FC	7.25a	6.98	7.03b	6.99b	6.62	6.27b	6.15b
Sources of organic material							
Rice straw	7.04c	6.82c	7.17ab	7.19a	6.82a	6.49a	6.34b
Rice root	7.14bc	6.92bc	7.14b	7.09c	6.70b	6.31b	6.33b
Cowdung	7.17ab	6.99ab	7.15b	7.14b	6.75b	6.37b	6.39b
Poultry manure	7.27a	7.11a	7.22a	7.20a	6.81a	6.48a	6.53a
Doses of organic material (t C ha^{-1})							
0.0	7.17	6.92	7.19	7.16b	6.75b	6.33c	6.32b
0.5	7.17	6.96	7.16	7.14bc	6.74b	6.33c	6.20c
1.0	7.16	6.94	7.13	7.14bc	6.76b	6.37bc	6.32b
1.5	7.12	6.99	7.17	7.13c	6.79b	6.45b	6.40b
2.0	7.16	6.99	7.19	7.20a	6.89a	6.58a	6.75a
CV(%)	3.13	3.98	1.29	0.81	1.84	2.92	2.45

AWD-alternate wetting and drying, FC-flooding condition; the means in column bearing same letters do not differ significantly ($p<0.05$, NS-non-significant).

Table 8. Effect of water and residues management practices on grain and straw yield of rice

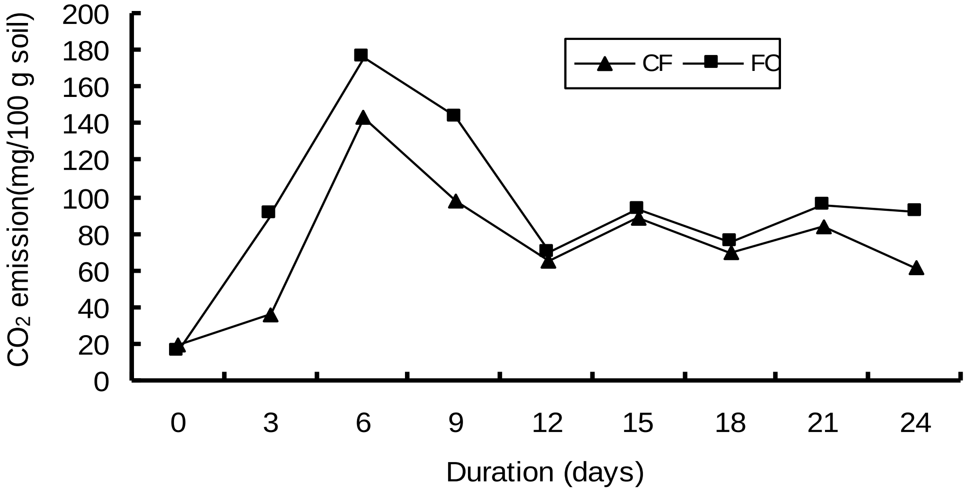
Treatment	Yield (g pot^{-1}) 2010		Yield (g pot^{-1}) 2011	
	Grain	Straw	Grain	Straw
Water regime				
AWD	11.37b	14.05b	16.58	22.71
FC	13.18a	17.39a	21.16	25.57
Source of organic materials				
Rice straw	11.79	15.20bc	19.46	23.66
Rice root	12.23	14.22c	18.27	26.69
Cowdung	12.45	16.37ab	17.59	22.34
Poultry manure	12.61	17.07a	20.15	23.85
Doses of organic materials (t ha^{-1})				
0.0	2.79c	2.74b	7.4	8.49c
0.5	13.89b	18.28a	18.08	26.82b
1.0	13.68b	18.78a	20.51	26.35b
1.5	14.51b	18.60a	23.05	29.90ab
2.0	16.49a	20.20a	25.32	32.13a
CV(%)	12.10	21.59	12.33	34.38

AWD-alternate wetting and drying, FC-flooding condition; the means in column bearing same letters do not differ significantly ($p<0.05$, NS-non-significant).

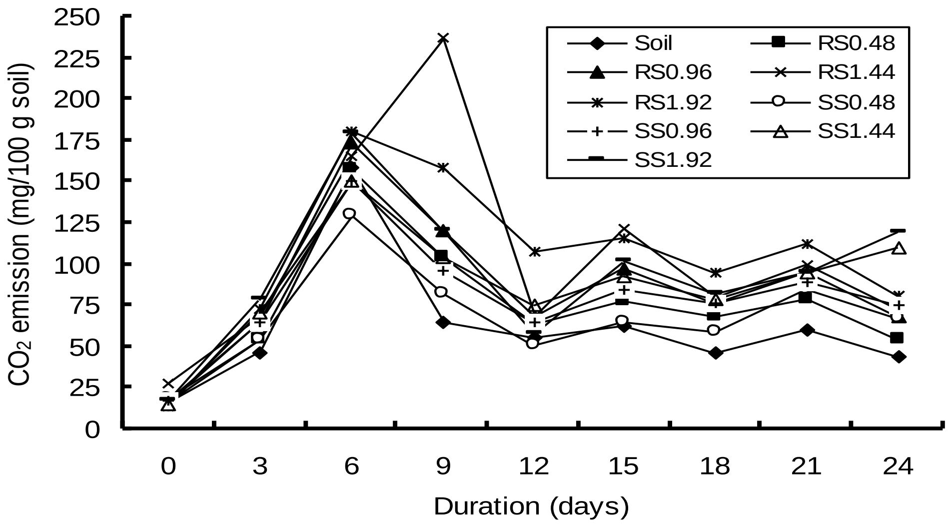
10.4. Carbon accumulation efficiency in soil using C_3 and C_4 crop residues

Effect of water levels on carbon dioxide carbon emission is presented (Graph 2). Maximum carbon dioxide carbon emission (177.01 and 144.12 mg 3 d^{-1} 100 g^{-1} soil) was found at 6 days after incubation in field capacity of soil and continuous flooding conditions respectively then it was decreased with the increase of time. Field capacity of soil enhanced the oxidation process of organic residues during incubation periods. Carbon emission rate was lower in continuous flooding condition than field capacity of soil. Organic residue decomposers need oxygen for their respiration process during decomposition. In this regard, continuous flooding condition created anaerobic status in soil. Effect of C_3 and C_4 crop residues on carbon dioxide carbon emission rate is presented (Graph 3). Organic residue with mixed of soil significantly increased carbon emission over soil alone. Rice straw produced the highest CO_2-C evolution from 0 to 24 days of incubation. Control treatment performed the lowest CO_2-C emission during the entire period of incubation study except 6th day. Maximum carbon dioxide carbon emission (237.42 mg 3 d^{-1} 100 g^{-1} soil) was found in RS at the rate of 1.44 t C ha^{-1} treatment at 9 days after incubation and the lowest carbon dioxide carbon emission (14.36 mg 3 d^{-1} 100 g^{-1} soil) was obtained from RS at the rate of 1.92 t C ha^{-1}. Carbon dioxide carbon emission was decreased with the increase of time. CO_2-C emission was decreased

after 6 days of incubation except RS at the rate of 1.44 t C ha^{-1} at 9 days after incubation. Interaction results revealed that mixing of organic residues with soil and different levels of water significantly affected the rate of CO_2-C emission (Table 9). Different doses of organic residues produced the maximum CO_2-C rate over soil alone. Maximum CO_2-C emission was observed in 6 and 9 days after incubation. RS and SS @ 1.92 t C ha^{-1} with field capacity of soil produced the highest CO_2-C gas. Based on the mean value results, sugarcane residue was more stabilized (42%) than rice straw in respect of decomposition rate.



Graph 2. Effect of different moisture levels on carbon dioxide carbon emission at different durations in pot experiment



Graph 3. Effect of organic residues on carbon dioxide carbon emission at different durations in pot experiment

Table 9. Interaction effect between different water and residues levels on carbon dioxide carbon emission (mg 100^{-1} g soil)

Treatment	0	3	6	9	12	15	18	21	24
W_1×Soil	19.80	33.00	139.33	61.60	50.00	60.00	55.00	55.00	47.67
W_1×RS0.48	18.48	29.15	147.58	106.34	60.50	75.17	66.00	71.50	47.67
W_1×RS0.96	16.50	35.20	159.50	113.67	60.50	91.67	73.33	91.67	60.50
W_1×RS1.44	35.31	28.60	150.34	122.83	47.50	115.50	78.83	91.67	69.67
W_1×RS1.92	15.51	35.20	154.00	135.67	110.00	128.33	84.34	108.17	75.17
W_1×SS0.48	18.48	31.90	114.59	67.84	42.17	67.83	62.33	80.67	49.50
W_1×SS0.96	16.83	39.60	132.00	75.17	56.83	69.67	71.50	84.34	58.67
W_1×SS1.44	15.18	44.55	130.17	95.33	66.00	82.50	66.00	91.67	75.17
W_1×SS1.92	18.48	50.60	169.59	102.67	49.50	106.34	78.84	82.50	69.67
W_2×Soil	13.20	60.50	177.83	68.20	60.00	65.00	36.67	66.00	40.33
W_2×RS0.48	14.19	79.75	166.84	102.67	66.00	80.67	71.50	86.17	60.50
W_2×RS0.96	16.83	94.60	187.00	126.50	75.17	102.67	78.83	99.00	77.00
W_2×RS1.44	20.46	108.35	179.67	352.00	89.84	128.34	80.67	108.17	77.00
W_2×RS1.92	13.20	110.00	206.25	181.50	106.33	102.67	104.50	117.34	86.17
W_2×SS0.48	19.14	77.00	145.75	97.17	58.67	62.34	56.83	88.00	84.33
W_2×SS0.96	18.48	90.20	168.62	117.34	73.33	99.00	80.67	93.50	91.67
W_2×SS1.44	13.86	95.70	171.42	113.67	84.34	102.67	91.67	97.17	144.84
W_2×SS1.92	15.51	106.70	189.75	137.50	66.00	97.17	86.17	106.17	168.67
CV(%)	38.84	6.06	6.33	49.45	21.90	49.45	9.82	9.56	33.47

10.5. Carbon sequestration in soils under different tillage, crop establishment method and rice straw management

Effect of tillage systems on carbon dioxide emission, organic carbon, yield of rice and N, P, K results are presented (Table 10, 11, 12, 13 and 14). Higher CO_2-C emission was observed in traditional tillage (TT) practice than minimum tillage (MT). Maximum CO_2-C emission was observed up to 90 days in T. aman 2010, 2011 and Boro 2010-11 and up to 120 days in Boro 2011-12 and T. aman 2012 thereafter its emission was decreased up to 150 DAT in all the studied years. In Boro 2011-12 and T. aman 2012, higher CO_2-C emission was found than other studied years. From these results it may be concluded that active pool of organic matter accumulated in these two years from earlier applied crop residues because its turnover time is 10 years. Higher organic carbon contents (0.79, 1.12, 1.66 and 1.77%) were found in minimum tillage than traditional tillage in T. aman 2010, 2011, 2012 and Boro 2011-12, respectively. Traditional tillage produced the higher grain yield of rice in T. aman 2010, 2011, 2012 and Boro 2010-11 than minimum tillage.

Minimum tillage produced maximum nitrogen content in post harvest soil in T. aman 2010 and 2011 (Table 14). Similar trend was observed in phosphorus and potassium content in soil. Effect of crop residue practices on carbon dioxide emission, organic carbon, yield of rice and N, P, K results are presented (Table 10, 11, 12, 13 and 14). Rice straw mulch practice mean value of carbon dioxide carbon emission (30.38, 24.75, 148.94 and 180.75 kg ha^{-1} d^{-1}) was found in T. aman 2010, 2011, 2012 and Boro 2011-12 except Boro 2010-11. The minimum CO_2-C emission was obtained from no residue treated plots in all the years. In T. aman 2012, maximum organic carbon content (1.81%) was observed in rice straw mulch treated plots followed by incorporation of rice straw treated plots (Table 12). In Aman season, maximum grain yield (4.97 t ha^{-1}) was found in no residue management treated plots in 2011 and the second highest grain yield was observed in rice straw incorporation treated plots in 2011. Rice straw incorporation produced the highest nitrogen content in post harvest soil in T. aman 2010 and 2011 (Table 14). Lowest nitrogen content was found in no residue management treatment in all the studied years. Similar trend was observed in phosphorus and potassium content in post harvest soil.

Interaction effect between tillage and residue management practices on carbon dioxide emission, organic carbon, yield of rice and N, P, K results are presented (Table 10, 11, 12, 13 and 14). Maximum CO_2-C emission was observed from 10 to 90 DAT and thereafter it was decreased from 90 to 150 DAT in T. aman 2010, 2011 and Boro 2010-11. In T. aman 2010, maximum CO_2-C evolution was observed in traditional tillage with incorporation of rice straw at 90 DAT. Minimum tillage without organic residue produced the lowest CO_2-C from 10 to 150 DAT. At 120 DAT, highest CO_2-C was emitted from minimum tillage with mulch of rice straw. From these results it may be concluded that tillage method with organic residue management influenced the CO_2-C emission in rice field. In Boro 2011-12 and T. aman 2012, traditional tillage with rice straw mulch produced the highest carbon dioxide carbon and the lowest carbon dioxide carbon was obtained from minimum tillage with rice straw incorporation treatment. Traditional tillage with no rice straw treated plot produced the lowest organic carbon content in T. aman 2010 and Boro 2011-12 (Table 13). On the other hand, minimum tillage with rice straw incorporation produced the maximum organic carbon content in T. aman 2010, 2012 and Boro 2011-12 except Boro 2010-11 and T. aman 2011. Maximum grain yield of rice (4.87, 5.45 and 4.58 t ha^{-1}) was observed in traditional tillage with rice straw incorporation treated plots in T. aman 2010, 2012 and Boro 2010-11, respectively. Highest nitrogen (0.077 and 0.40%) and K (58.50 and 64.68 ppm) was found in minimum tillage with rice straw mulch and phosphorus content in traditional tillage with no rice straw management practice in T. aman 2010 and 2011, respectively. Therefore, these results indicated that integrated use of minimum tillage and rice straw incorporation or mulch improved soil quality and reduced carbon dioxide emission (Six *et al.*, 2002).

Table 10. Effect of different tillage and residue management practices on carbon dioxide carbon

Crop season	Treatment	Duration (days)						
		10	30	60	90	120	150	Mean
		(kg CO_2-C d^{-1} ha^{-1})						
T.aman - 2010	MT	10.89	16.51	24.54	42.54	42.18	29.24a	27.65
	TT	11.44	17.73	27.83	43.74	41.75	27.63b	28.35
	NRS	9.78b	14.60c	24.13b	40.89b	37.57c	20.70c	24.61
	RSI	11.72a	19.54a	26.45a	45.45a	42.70b	28.22b	29.01
	RSM	11.99a	17.24b	27.97a	43.08ab	45.63a	36.38a	30.38
	CV(%)	*7.99*	*8.67*	*9.73*	*7.17*	*4.88*	*5.37*	-
Boro -2010 - 11	MT	31.24	27.99	17.24b	15.84	12.63	12.66	19.60
	TT	32.52	28.50	18.48a	16.93	13.64	13.73	20.63
	NRS	28.70b	29.93	18.06	17.36a	13.76a	13.00a	20.14
	RSI	33.55a	28.92	18.41	18.38a	14.64a	14.80a	21.45
	RSM	33.38a	28.90	17.12	12.41b	10.01b	9.99b	18.64
	CV(%)	*5.51*	*6.55*	*7.22*	*8.30*	*8.59*	*8.22*	-
T.aman - 2011	MT	17.82	27.89	31.74	47.33	6.18b	5.49b	22.74
	TT	17.05	26.46	36.68	47.06	8.04a	7.92a	23.87
	NRS	15.33b	25.21b	30.58c	45.09b	6.17b	5.99b	21.40
	RSI	16.44b	25.51b	32.93b	50.25a	9.08a	8.40a	23.77
	RSM	20.53a	30.77a	39.13a	46.24b	6.09b	5.73b	24.75
	CV(%)	*9.27*	*6.62*	*6.37*	*3.33*	*5.57*	*6.40*	-
Boro – 2011 - 12	MT	113.00	111.02	153.72	109.23	166.67	155.03	134.78
	TT	127.71	152.88	187.52	106.03	149.16	144.86	144.69
	NRS	110.64	85.57	178.16	107.39	170.73	137.54	131.67
	RSI	118.93	122.09	182.28	107.17	135.58	165.56	138.60
	RSM	131.50	188.19	151.42	108.33	167.45	146.73	148.94
	CV(%)	*32.34*	*55.13*	*25.54*	*8.87*	*42.41*	*14.41*	-
T.aman - 2012	MT	151.21b	205.97a	228.67	142.59	166.67a	109.23	167.39
	TT	183.07a	227.21b	227.54	147.45	149.16b	106.03	173.41
	NRS	76.29c	156.02c	220.96b	147.52	160.73a	105.39	144.49
	RSI	225.69a	255.62a	225.16b	139.58	125.58b	104.18	179.30
	RSM	199.44b	238.12b	238.20a	147.98	157.45a	103.32	180.75
	CV(%)	*5.42*	*4.50*	*3.35*	*5.11*	*4.59*	*3.93*	-

MT = minimum tillage, TT = traditional tillage, NRS = no residues, RSI = rice straw incorporation and RSM = rice straw mulch; the means in column bearing same letters do not differ significantly ($p<0.05$, NS = non-significant).

Table 11. Interaction effect between different tillage and residue management practices on carbon dioxide carbon emission

Crop season	Treatment	Duration (days)						
		10	30	60	90	120	150	Mean
		(kg CO_2-C d^{-1} ha^{-1})						
T. aman – 2010	MT × NRS	9.18	13.47	22.12c	40.25	36.72	20.67	23.74
	MT × RSI	11.74	19.57	24.78bc	44.34	44.07	29.78	29.05
	MT × RSM	11.75	16.50	26.70ab	43.01	45.75	37.27	30.16
	TT × NRS	10.38	15.73	26.12ab	41.53	38.41	20.72	25.48
	TT × RSI	11.85	19.50	28.12ab	46.56	41.32	26.67	29.00
	TT × RSM	12.24	15.91	29.23a	43.14	45.51	35.49	30.25
	CV(%)	*7.99*	*8.67*	*9.73*	*7.17*	*4.88*	*5.37*	-
Boro 2010 – 11	MT × NRS	25.85c	30.40	17.36	17.79a	14.23	14.24a	19.98
	MT × RSI	34.66a	28.18	17.96	17.83a	13.98	14.29a	21.15
	MT × RSM	33.20ab	28.40	16.41	11.90b	9.50	9.45b	18.14
	TT × NRS	31.56b	29.45	18.76	18.93a	15.28	15.35a	21.56
	TT × RSI	32.44ab	29.66	18.85	18.93a	15.11	15.31a	21.72
	TT × RSM	33.56ab	29.33	17.83	12.92b	10.52	10.54b	19.12
	CV(%)	*5.51*	*6.55*	*7.22*	*8.30*	*8.59*	*8.22*	-
T. aman - 2011	MT× NRS	15.32	24.00d	27.98d	44.55	5.91bc	5.66c	20.57
	MT× RSI	16.40	25.82bcd	29.36d	50.65	6.27bc	5.74c	22.37
	MT× RSM	21.73	33.87a	38.64ab	46.79	6.36b	5.08d	25.41
	TT × NRS	15.33	26.47bc	33.94c	45.63	6.42b	6.33b	22.35
	TT × RSI	16.47	25.19cd	36.49bc	49.86	11.88a	11.06a	25.16
	TT × RSM	19.33	27.67b	39.59a	45.68	5.81c	6.38b	24.08
	CV(%)	*9.27*	*6.62*	*6.37*	*3.33*	*5.57*	*6.40*	-
Boro 2011 – 12	MT× NRS	102.05	106.94	168.36	112.64	195.73	146.77	138.75
	MT× RSI	114.88	140.53	165.35	110.45	118.41	166.42	136.01
	MT× RSM	122.07	185.58	127.45	104.59	186.02	151.89	146.27
	TT × NRS	119.23	164.20	187.95	102.13	145.86	128.32	141.28
	TT × RSI	122.98	103.65	199.22	103.90	152.75	164.70	141.20
	TT × RSM	140.93	290.80	175.39	112.06	148.88	141.56	168.27
	CV(%)	*32.34*	*55.13*	*25.54*	*8.87*	*42.41*	*14.41*	-
T. aman – 2012	MT× NRS	78.87e	157.74d	229.74b	144.18	195.59a	107.64a	152.29
	MT× RSI	233.23b	260.64b	226.32b	138.36	118.41c	106.45ab	180.57
	MT× RSM	141.52d	199.51c	229.93b	145.25	186.01a	104.59bc	167.80
	TT × NRS	73.70e	154.29d	212.17c	150.85	145.86b	100.14c	139.50
	TT × RSI	218.16c	250.60b	223.99b	140.80	152.75b	108.90c	182.53
	TT × RSM	257.35a	276.73a	246.47a	150.71	148.88b	110.06a	198.37
	CV(%)	*5.42*	*4.50*	*3.35*	*5.11*	*4.59*	*3.93*	-

MT = minimum tillage, TT = traditional tillage, NRS = no residues, RSI = rice straw incorporation and RSM = rice straw mulch; the means in column bearing same letters do not differ significantly ($p<0.05$, NS = non-significant).

Table 12. Effect of tillage and residues management practices on organic carbon status in soil

Treatment	2010 (T. aman)	2010-11 (Boro)	2011 (T. aman)	2011-12 (Boro)	2012 (T. aman)
Tillage system					
MT	0.79	1.11	1.21a	1.66a	1.77a
TT	0.77	1.12	1.13b	1.44b	1.59b
Rice straw management					
NRS	0.72b	1.10b	1.16b	1.29b	1.44b
RSI	0.84a	1.19a	1.30a	1.68a	1.80a
RSM	0.78b	1.06b	1.04c	1.68a	1.81a
Interaction					
MT × NRS	0.73	1.19ab	1.28a	1.29d	1.36d
MT × RSI	0.85	1.15ab	1.28a	1.99a	1.99a
MT × RSM	0.79	0.99c	1.06b	1.72b	1.96a
TT × NRS	0.72	1.02c	1.04b	1.29d	1.52c
TT × RSI	0.82	1.23a	1.32a	1.38c	1.60bc
TT × RSM	0.77	1.12b	1.02b	1.64b	1.66b
CV(%)	10.85	5.90	2.85	3.59	4.26

MT = minimum tillage, TT = traditional tillage, NRS = no residues, RSI = rice straw incorporation and RSM = rice straw mulch; the means in column bearing same letters do not differ significantly ($p<0.05$, NS = non-significant).

Table 13. Effect of tillage and residues management practices on grain and straw yield of rice

Treatment	2010 (T.aman)		2010-11 (Boro)		2011 (T.aman)		2011-12 (Boro)		2012 (T.aman)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
	(t ha^{-1})									
Tillage method										
MT	4.31	4.53	5.15	5.21	4.87	5.29	5.03	5.79	3.84	3.63
TT	4.67	4.82	5.18	5.56	4.92	5.43	5.00	6.27	4.23	4.17
Rice straw management										
NRS	4.59a	4.79a	5.19a	5.30b	4.97	5.60	5.40	6.38	4.05	3.83
RSI	4.57a	4.64b	5.24a	5.64a	4.88	5.54	4.84	5.59	4.19	4.14
RSM	4.32b	4.60c	5.06b	5.22c	4.81	4.95	4.80	6.13	3.89	3.73
Interaction										
MT × NRS	4.52c	4.50d	5.00b	5.20c	5.07	5.78	5.44	6.00	3.85	3.18
MT × RSI	4.27d	4.37e	5.04b	5.31b	5.00	5.39	4.76	5.63	3.80	4.10
MT × RSM	4.15e	4.67c	5.41a	5.12c	4.53	4.70	4.90	5.75	3.93	3.60
TT × NRS	4.66b	5.04a	5.38a	5.40b	4.90	5.41	5.37	6.75	4.25	4.48
TT × RSI	4.87a	4.90b	5.45a	5.96a	4.77	5.69	4.93	5.55	4.58	4.18
TT × RSM	4.48c	4.53d	4.71c	5.32b	5.10	5.20	4.70	6.50	3.85	3.85
CV(%)	*1.65*	*0.50*	*1.07*	*1.25*	*7.56*	*13.39*	*15.61*	*23.57*	*15.50*	*15.96*

MT = minimum tillage, TT = traditional tillage, NRS = no residues, RSI = rice straw incorporation and RSM = rice straw mulch; the means in column bearing same letters do not differ significantly ($p<0.05$, NS = non-significant).

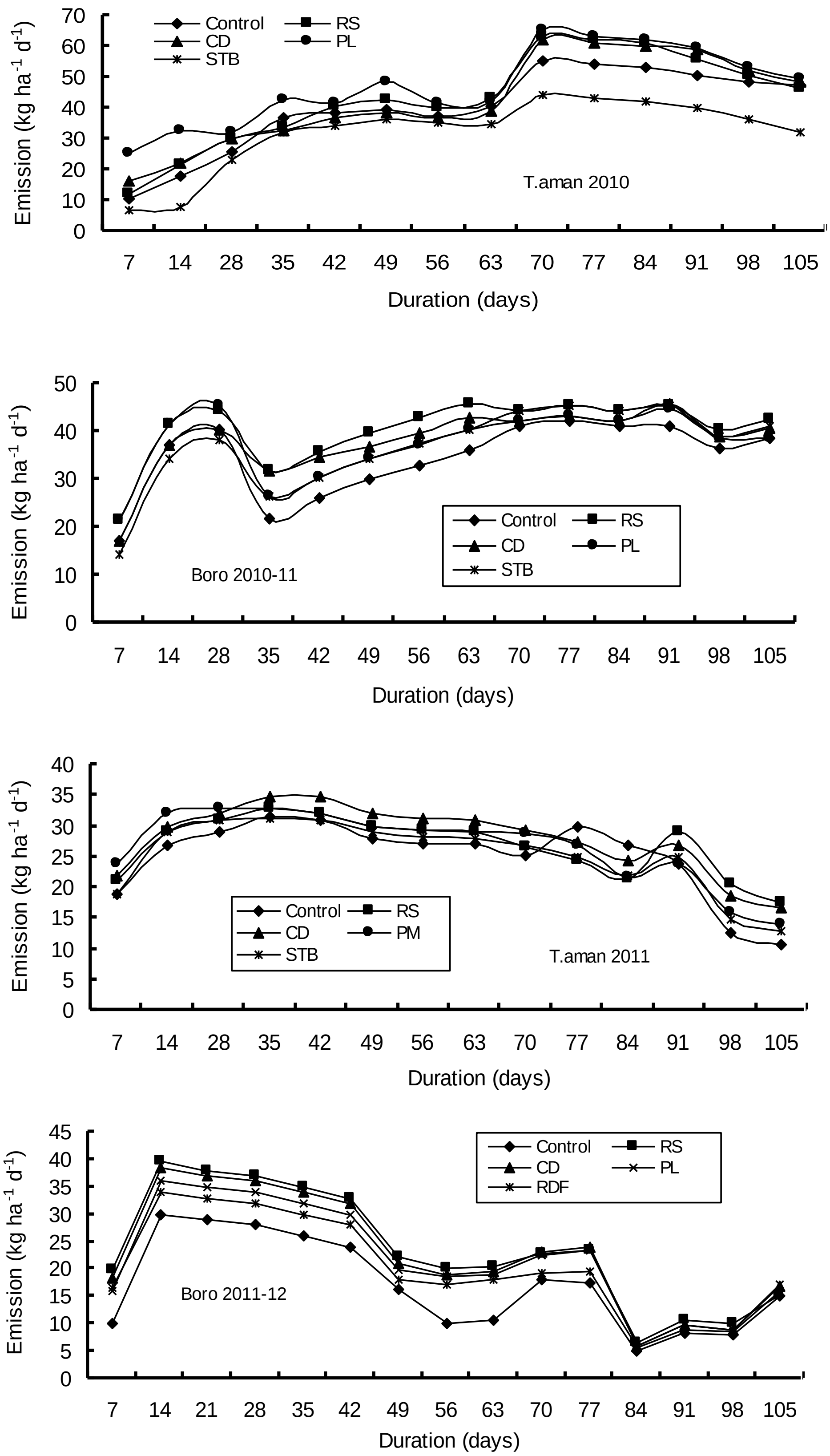
Table 14. Effect of different tillage and residue management practices on NPK content in post harvest soil

Treatment	N (%)			P (ppm)			K (ppm)		
	2010	2010-11	2011	2010	2010-11	2011	2010	2010-11	2011
Tillage methods									
MT	0.066	0.36	0.37a	198.64	136.29b	154.59	55.50a	62.12	59.29b
TT	0.064	0.37	0.36b	193.60	143.41a	149.45	51.92b	63.33	64.14a
Residues management									
NRS	0.063b	0.32b	0.35b	194.78b	146.34a	143.93b	51.00b	63.46	61.85
RSI	0.068a	0.38a	0.38a	214.78a	131.98b	167.35a	57.13a	62.45	63.87
RSM	0.064b	0.40a	0.37a	178.81c	141.23a	144.78b	53.00b	62.25	59.42
Interaction									
MT×NRS	0.063c	0.31d	0.35cd	213.09ab	142.33	155.08	55.58ab	65.89	62.66ab
MT×RSI	0.063c	0.32cd	0.34d	176.46cd	150.35	132.78	46.42c	61.04	61.04b
MT×RSM	0.077a	0.39ab	0.40a	209.73b	127.20	164.64	58.50a	61.44	64.68ab
TT×NRS	0.059c	0.37b	0.36bc	219.82a	136.76	170.07	55.75ab	63.46	63.06ab
TT×RSI	0.059c	0.37b	0.37b	173.09d	139.33	144.04	52.42b	59.02	50.53c
TT×RSM	0.070b	0.44a	0.37b	184.53c	143.13	145.52	53.58b	65.49	63.10a
CV (%)	4.96	7.13	3.24	3.21	4.84	8.39	5.39	8.43	6.78

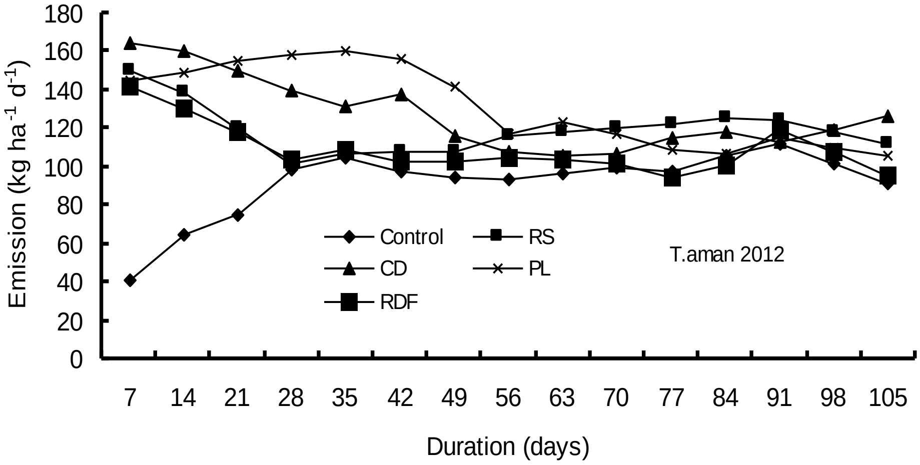
MT = minimum tillage, TT = traditional tillage, NRS = no residues, RSI = rice straw incorporation and RSM = rice straw mulch; the means in column bearing same letters do not differ significantly ($p<0.05$, NS = non-significant).

10.6. Effects of different organic manures/residues and fertilizer management on carbon sequestration under rice – rice cropping pattern

Effect of integrated plant nutrient system with organic residues, soil test based fertilizer recommendation including control on CO_2-C emission, rice yield, organic carbon and nutrient content results are presented (Graph 4: T. aman 2010, Boro 2010-11, T. aman 2011 and Boro 2011-12, Graph 5: T. aman 2012, Table 15, 16 and 17). In T. aman 2010, maximum carbon dioxide carbon emission was found at 70 days after transplanting (DAT) of rice. Poultry litter released the maximum CO_2-C followed by cowdung and rice straw. Lowest CO_2-C emission was observed in soil test based of chemical fertilizer (STB) during entire growth period. Control plot produced more CO_2-C than soil test based fertilizers treated plot. Among the organic amendments, maximum CO_2-C was emitted from poultry manure treated plots and the lowest CO_2-C was emitted from rice straw treated plots. In Boro 2010-11, the lowest CO_2-C was released from soil test based fertilizers treated plot from 7 to 28 DAT of rice. From 28 to 35 DAT, CO_2-C emission was decreased in all the treatments. After 35 days, all the treatment increased significant amount of CO_2-C with the increase of time. In T. aman 2011, poultry litter produced the maximum CO_2-C from 7 to 28 days after transplanting of rice. Cowdung released the highest CO_2-C from 35 to 70 days. From 91 days CO_2-C emission was decreased up to 105 days after transplanting of rice by all treatments. In Boro 2011-12, maximum CO_2-C emission was found in 14 days after transplanting of rice. Control plot produced the lowest CO_2-C during the entire growth period of rice. In Boro 2012, minimum CO_2-C was evolved from control plot and the maximum CO_2-C produced in poultry litter treated plot. Maximum grain yield was observed in soil test based fertilizers in Boro 2010-11, 2011-12 and T. aman 2011 (Table 15). On the other hand, poultry litter produced the highest grain yield of rice in T. aman 2010 and 2012. Control treatment produced the lowest grain yield of rice in five crop seasons. In T. aman 2010 and 2012, maximum organic carbon content (0.88 and 1.19%) was obtained from rice straw and poultry manure treated plot respectively (Table 16). On the other hand, cowdung produced the highest organic carbon content (1.01 and 1.12%) in Boro 2010-11 and T. aman 2011. Control treatment produced the lowest organic carbon content 0.72, 0.86, 0.86, 0.84 and 0.88% in T. aman 2010, 2011, 2012 and Boro 2010-11, 2011-12 respectively but organic carbon content slightly increased from T. aman 2010 to 2012. STB treated plot also increased organic carbon content in soil. From these results it may be concluded that continuous cropping systems helped to increase organic carbon content in soil compared to fallow condition. In T. aman 2010, organic residues produced the higher nitrogen content in soil than control treatment. In Boro 2010-11, maximum nitrogen content was also obtained from recommended dose of chemical fertilizer treated plot. STB produced the reasonable amount of phosphorus content in post harvest soil in T. aman 2010 and rice straw and poultry manure produced maximum phosphorus in Boro 2010-11. Rice straw also produced the highest potassium (20.51 and 37.61 ppm) in T. aman 2010 and 2011, respectively.



Graph 4. Effect of different organic residues and mineral fertilizer on CO_2-C emission (T. aman 2010, Boro 2010-11, T. aman 2011 and Boro 2011-12, respectively)



Graph 5. Effect of different organic residues and mineral fertilizer on CO_2-C emission in T. aman 2012

Table 15. Effect of organic and chemical fertilizers on grain and straw yield of rice

Treatment	Yield (t ha^{-1})									
	2010		2010-11		2011		2011-12		2012	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Control	2.80b	3.57c	3.15e	1.98	2.55c	3.11d	2.55d	2.50d	2.64	3.52
RS	3.66a	4.38bc	5.23d	4.08	4.27ab	5.68a	6.45ab	5.33bc	3.50	5.05
CD	3.61a	4.10c	6.25c	4.26	4.21ab	5.18ab	4.73c	4.38c	3.26	3.91
PM	4.05a	6.03a	6.53b	4.99	3.75b	4.53c	5.73b	5.38b	3.92	5.84
STB	4.01a	5.45ab	6.70a	5.69	4.32a	4.88c	7.24a	6.43a	2.73	4.44
CV(%)	12.42	15.56	10.76	NS	9.51	8.90	10.67	13.11	25.85	19.40

MT = minimum tillage, TT = traditional tillage, NRS = no residues, RSI = rice straw incorporation and RSM = rice straw mulch; the means in column bearing same letters do not differ significantly ($p<0.05$, NS = non-significant).

Table 16. Effect of organic and chemical fertilizers on organic carbon status in post harvest soil

Treatment	OC (%)	C-load (t ha^{-1})	OC (%)	C-load (t ha^{-1})	OC (%)	C-load (t ha^{-1})	OC (%)	C-load (t ha^{-1})	OC (%)	C-load (t ha^{-1})
	2010		2010-11		2011		2011-12		2012	
Control	0.72	-	0.84	-	0.86c	-	0.88c	-	0.86c	-
RS	0.88	1.6	0.93	0.9	0.98b	0.12	1.17ab	0.29	1.18a	0.32
CD	0.80	0.8	1.01	1.7	1.12a	1.06	1.18ab	0.30	1.03a	0.17
PM	0.79	0.7	0.91	0.7	0.96b	0.97	1.14a	0.26	1.19ab	0.33
STB	0.76	0.4	0.88	0.04	0.92bc	0.06	0.98ab	0.11	1.11b	0.25
CV(%)	NS	-	NS	-	4.83	-	8.03	-	9.27	-

OC = Organic carbon, RS = rice straw, CD = cowdung, PM = poultry manure and STB = soil test based chemical fertilizer; the means in column bearing same letters do not differ significantly ($p<0.05$, NS-non-significant).

Table 17. Effect of organic and chemical fertilizers on NPK content in post harvest soil

Treatment	N (%)			P (ppm)			K (ppm)		
	2010	2010-11	2011	2010	2010-11	2011	2010	2010-11	2011
Control	0.070c	0.080c	0.092d	46.38	42.05	30.08a	19.16	40.96	34.64
RS	0.090a	0.090bc	0.140a	55.34	48.00	36.08c	20.51	56.75	37.61
CD	0.090a	0.085bc	0.110bc	54.11	43.78	35.70b	19.94	66.69	27.12
PM	0.090a	0.100ab	0.120b	56.17	48.00	36.53ab	20.33	63.32	27.62
STB	0.080b	0.110a	0.100cd	57.03	43.35	38.25d	19.16	64.61	36.57
CV (%)	8.69	6.80	8.27	NS	NS	12.59	NS	NS	NS

RS = rice straw, CD = cowdung, PM = poultry manure and STB = soil test based chemical fertilizer; the means in column bearing same letters do not differ significantly ($p<0.05$, NS-non-significant).

11. Research highlights

- Soil bulk density was decreased with the increase of soil depth. Soil organic carbon content decreased with the increase in soil depth irrespective of land types. The SOC content (%) and stock (t ha^{-1}) were found higher in the very lowland than in highland, medium highland and medium lowland. Among the 10 AEZs, the highest SOC stock (1.40 million tones ha^{-1}) was found in AEZ 13 irrespective of land types.

- In incubation study, moistened condition produced higher rate and cumulative CO_2–C emission than flooding condition. However, among the organic materials poultry manure with soil emitted more CO_2–C than cowdung, rice straw and rice root with soil. Maximum carbon degradation rate was found in soil alone treated pot.

- In pot experiment, flooding condition produced higher grain yield than alternate wetting and drying condition. Continuous flooding condition was found more efficient to accumulate SOC (%) in soils than alternate wetting and drying condition. Among the organic residues doses, 2.0 t C ha^{-1} produced the maximum organic carbon content in soil.

- In incubation study, rice straw produced more CO_2–C than sugarcane straw. Sugarcane residue (C_4) stabilized (42%) more carbon in soil than rice straw (C_3) residue.

- In field experiment at Ishurdi, minimum tillage produced the maximum SOC in soil. Rice straw incorporation and mulch significantly produced SOC (17 and 10%) over no crop residue treated plots respectively after five crop seasons. Minimum tillage sequestrated the maximum SOC (0.039 t C ha^{-1} yr^{-1}) over traditional tillage. Recommended dose of chemical fertilizer treated plots produced the highest grin yield of rice.

- In field experiment at Mymensingh, rice straw, cowdung, poultry manure and STB fertilizers produced 24, 24, 20 and 12% more organic carbon over control treatment after five crop seasons. Poultry manure treated plots produced the higher grain yield of rice than other treatments.

12. Environmental Screening Matrix: Agricultural Research under SPGR (Before & after information)

Sl. No.	Environmental issue	Component	Improvement/Deterioration*				Remarks
			Small	Moderate	Large	None	
1	**Biodiversity**	Flora			+		
		Fauna			+		
		Genetic diversity	+				
		Exotic varieties				none	
		Local varieties/cultivars				none	
		Hybrids				none	
2	**Soil quality**	Organic matter	before		+		
			after		++		
		Chemical fertilizer use	before		+		
			after		++		
		Soil salinity			+		
		Fertility status	before		+		
			after		++		
		Microbial activity			+		
		Heavy metal contamination				no	
		Water quality			+		
3	**Agro-Chemicals**	Pesticide use				no	
		POPs				no	
		IPM			+		
		Pest infestation				no	
		Bio-pesticides				no	
		Health hazard				no	
4	**Pollution**	Soil				no	
		Water				no	
		Air				no	

13. Major Attainments (in relation to the set objectives):

a. Technical:

Sl. No.	Major technical activities performed in respect of the approved objectives	Out-put (i.e. product obtained: visible/ measurable)	Outcome (short term effects of the research)	Impact (long term effect of the research)	Remarks
1.	Determination of bulk density and organic carbon stock	Higher organic carbon content in 0-5cm than other depths 5-10, 10-15 and 15-20cm of soil	Organic carbon content 7.88, 7.62, 7.11 and 6.75% in 0-5, 5-10, 10-15 and 15-20cm, respectively	Surface soil is suitable for crop production	
		Higher organic carbon stock is in very LL soil than other land types	Higher organic carbon stock is 8.54, 10.76, 13.84, 21.70, 29.69 t ha^{-1} in HL, MHL, MLL, LL and VLL, respectively	Land use and management practices should be carefully handled to enrich organic carbon for HL, MHL and MLL soil	
2.	Carbon sequestration and degradation rate without crop	Continuous flooding is better than field capacity in respect of CO_2-C emission and organic carbon in soil	Field capacity of soil produced 19.75 CO_2 and 1.98% more C and less organic carbon than continuous flooding	Continuous flooding helps to increased use efficiency of plant nutrition and organic residue increases nutrient content and productivity of soil	
		Organic residue is better than soil alone in respect of organic carbon	Organic carbon enriched 20.69, 17.82, 27.01 and 21.84% than control		
3.	Organic carbon stock, crop yield with crop	Continuous flooding is better than alternate wetting and drying system in respect of carbon sequestration	Continuous flooding produced 6.53% higher organic carbon than alternate wetting and drying system	Continuous flooding condition may be increased SOC in soil	
		Organic residues are better than control in respect of organic carbon stock	Increase organic carbon 6.16, 8.07,16.30 and 12.65% in 0.5, 1.0, 1.5 and 2.0 t C ha^{-1}, respectively	Organic residue increase organic carbon status to help nutrient availability for crop production	
4.	C_3 and C_4 crop residues decomposition rate	C_4 crop residue is better than C_3 crop residue	42% higher efficiency for carbon sequestration by C_4 crop residue	Increase nutrient adsorbed efficiency by C_4 crop residue	
5.	Tillage practice with rice straw management	TT is better than minimum tillage in respect of rice yield	TT yield increase 5% higher than minimum tillage		
		Minimum tillage, rice straw incorporation and mulch are better than traditional tillage with no use of rice straw	MT, rice straw incorporation and mulch increase 11.61, 19.84 and 12.07% organic C in soil.	Increase nutrient use efficiency and rice yield	
6.	Compare between organic residues and recommended dose of chemical fertilizer	Rice straw, cowdung, poultry litter and recommended dose of chemical fertilizer are better than control treatment in respect of yield	Rice straw, cowdung, poultry litter and RDF increase 67.89, 54.71, 78.89 and 82.90% better than control	Organic residues help to keep soil productivity for long duration	
		Rice straw, cowdung, poultry litter and recommended dose of chemical fertilizer are better than control treatment in respect of organic carbon	Rice straw, cowdung, poultry litter and RDF increased SOC 24, 24, 20 and 12% better over control		

b. Procurement

Sl. No.	Approved provisions of Procurement (list major items by category)	Achievement	% of achievement	Remarks
1.	**Lab equipments**	**-**	**-**	**All procurement materials: Active condition and presently used in**
	Gas Analyzer	1	100%	Soil Science Division, BINA
	Optifix dispenser	1	100%	ʺ
	GPS	1	100%	ʺ
	Auger and core sampler	1 set	100%	ʺ
2.	**Office equipment and furniture**			
	Laptop computer	1	100%	ʺ
	Digital Camera	1	100%	ʺ

c. HRD/Training:

Title (e.g. PhD/ Training, workshops conducted etc.)	Target	Attainments	No. of participants	Benefit of the higher studies/training (application of the learning, productivity enhancement	Remarks
HRD/Training provisions were not allocated in our project.					

d. Financial

Sl. No.	Major Head	Fund received (Tk.)	Expen diture (Tk.)	Unspent (Tk.)	Remarks
1.	Contractual staff salary	3750890.00	169800.00	Nil	
2.	Field research/Lab. Expenses and Supplies		1766342.00		
3.	Operating expenses		332138.00		
4.	Fuel, oil & maintenance		-		
5.	Training/Workshop/Seminars etc		-		
6.	Publications and Printing		50670.00		
7.	Contingencies		88718.00		
8.	Capital expenses		1343222.00		
Total		**37,50,890.00**	**37,50,890.00**	**Nil**	

e. Materials developed/Publications made:

Type of material/ publication	Title	No.	Remarks
Technology development	-	-	No
Process development	-	-	No
Information development	Significant amount of carbon sequestration is possible through different management practices in soil (conservation tillage, organic residues and water management). Soil carbon status map can produce of 30 AEZs of Bangladesh using these result findings.	-	
Journal publication	M.B. Hossain and A.B. Puteh. 2013. Emission of carbon dioxide influenced by different water levels from soil incubated organic residues. The Scientific World Journal. 2013 : 1-8. ID 638582. http://dx.doi.org/10.1155/2013/638582	1	Impact Factor: 1.730
Books/Monographs/ Manual/Communication material published	-	-	Not published
Booklet/Leaflet/Flyer etc published	-	-	Not published
Any other (patening of technology etc.)	-	-	No

14. Sub-project Auditing (cover all types of audit performed)

Type of audit (e.g. BARC/ Implementing agency/FAPAD/ World Bank/PCU hired firm/others)	**Major observations/ issues/objections raised, if any**	**Status of the audit objection at the sub-project end**	**Remarks**
FAPAD and J. U. Ahmed hired firm (NATP)	No audit objection raised	Satisfactory	-

15. Reporting

Report type	Actual date of submission(s)	Total No. (s)	Remarks
a. Inception report	06.06.10	1	
b. Monthly report	04.08.10, 06.11.10, 05.12.10, 10.01.10, 10.02.11, 02.03.11, 06.04.11, 05.05.11, 08.10.11(6), 08.12.11, 08.01.12, 08.02.12, 08.03.12, 08.04.12, 08.05.12, 08.06.12, 08.07.12, 08.08.12, 08.09.12, 08.10.12, 27.05.13(6)	31	
c. Statement of expdts. (SOE)*	03.07.10, 08.08.10, 08.09.10, 06.09.10, 06.11.10, 05.12.10, 10.01.11, 14.02.11, 02.03.11, 06.04.11, 05.05.11, 06.10.11, 08.10.11, 23.11.11(4), 23.07.12(8), 07.08.12, 07.09.12, 02.10.12, 27.05.13(7), 03.06.13, 22.09.13, 23.10.13, 25.05.14(2), 09.09.14, 08.12.14	42	
d. Quarterly report(s)*	06.12.10	1	
e. Six monthly report	05.12.10, 19.09.1	2	
f. Annual report	06.05.11, 06.07.12, 18.07.13	3	
g. Procurement plan	06.06.10	1	
h. Annual research program format	16.11.11	1	
i. Environmental monitoring (Annual basis)	11.11.12	1	
j. Social safeguard status (Annual basis)	11.11.12	1	
k. Field monitoring report(s)**		10	

***Provide all since start to end**
****Conducted at the local by implementing agencies**

16. Problems/Constraints:

1. Reporting of the project was too many.
2. Delay of fund disbursement also hampered to implement the project activities in time.

17. Suggestions for future, if any:

These research findings provide some suggestions on the following aspects:

1. Continuous monitoring system is needed on carbon status in 30 AEZs of Bangladesh soils for the development of effective land use plan.
2. Efficient nitrogen management practices are needed through carbon sequstration in soil
3. Optimum starter nitrogen dose is needed for inhibiting immobilization process of soil nitrogen after using different fresh organic residues in field.
3. Research should be adopted to fit balanced fertilization (inorganic and organic sources) for increasing crop production as well as improve soil organic carbon status.
4. To increase nutrient use efficiency, research should be strengthended to identify the effect of mixing organic residues dose (rice straw and legume hay) with chemical fertilizers for synchronizing nutrient supply with crop demand.
5. Microbial oriented research is needed to enhance carbon sequestration in soil through the development of soil aggregates.
6. Moisture conservation process should be developed through carbon sequestration in soils under drought prone areas.

Signature of the Principal Investigator

Date ……………………………………

Seal

Counter signature of the Head of the agency/authorized representative

Date ……………………………………

Seal

Annexure-1

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Annexure-2

Procurement status of capital items:

Sl. No.	List of items	Unit	Achievement (%)	Remarks
1.	**Lab equipments**	**-**	**-**	All procurement materials were procured according to the proposed research project.
	Gas Analyzer	1	100%	
	Optifix dispenser	1	100%	
	GPS	1	100%	
	Auger and core sampler	1 set	100%	
2.	**Office equipment and furniture**			
	Laptop computer	1	100%	
	Digital Camera	1	100%	

Signature of the Principal Investigator

Date: ....

Seal

Signature of the Head of the Institute

Date: ....

Seal

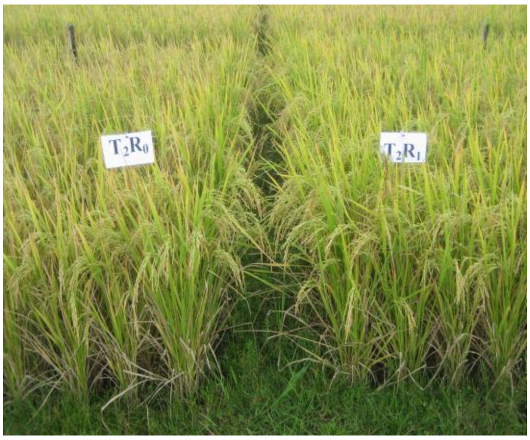
Pot experiment-BINA Headquarter

Field experiment at Ishurdi

Field experiment at Mymensingh

Australian Prof. visited our experiment

Pot experiment-BINA Headquarter

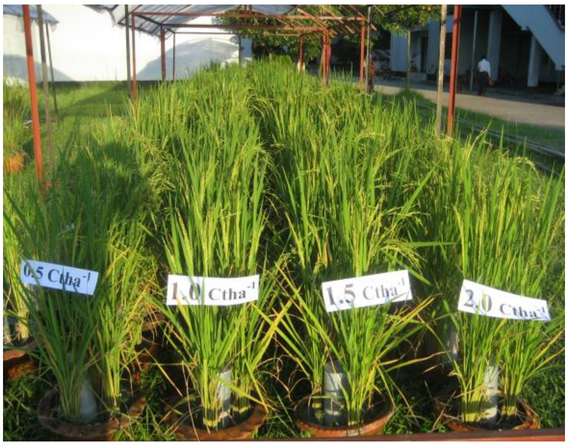


Field experiment at Ishurdi

Farmers' use cowdung as fuel purpose

Field experiment at Mymensingh

Field experiment at Mymensingh



Pot experiment-BINA Headquarter

Field experiment-BINA Headquarter

Field experiment at Ishurdi